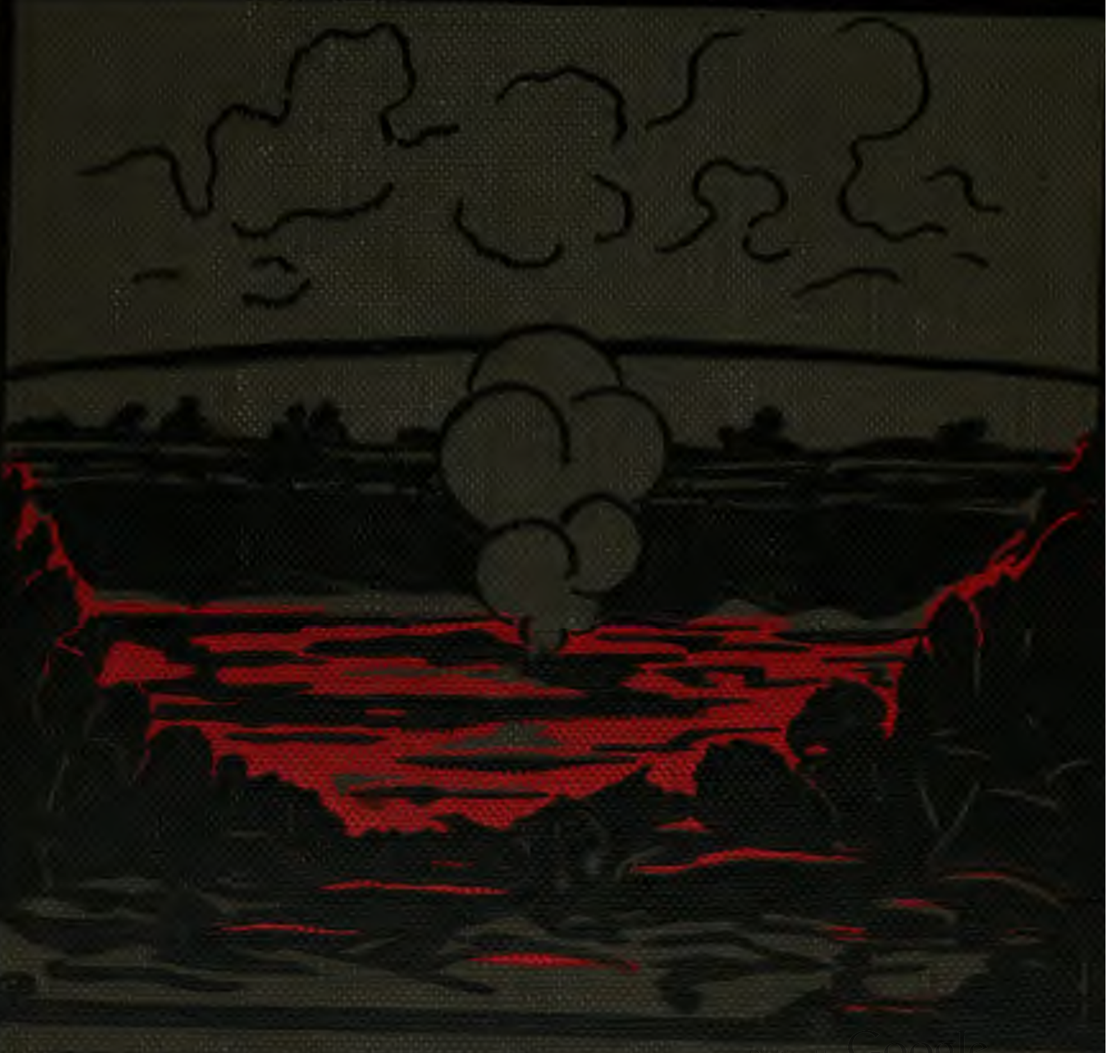
HAWAII AND ITS VOLCANOES



CHARLES H. HITCHCOCK LL.D.

S. B. Woodward.

Halemaumau in 1894.

Hawaii and Its Volcanoes

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PREFACE

The object of this book is to describe correctly the phenomena connected with the discharges of molten lava from the two great Hawaiian volcanoes—Kilauea and Mauna Loa. The greater part of the text presents the statements of visitors to their borders, descriptive of what they saw, set forth in chronological order. If there is some repetition of views, it is because the different observers came to similar conclusions.

It is presumed that all the Hawaiian volcanoes throughout the archipelago have been developed in a similar manner—starting at the bottom of the ocean there has been an outpouring of lava, gradually accumulating upwards. If the supply was inadequate these cones lost their vitality before reaching the surface of the water. In other cases the summits became the low coralline islands composed of the reefs aggregated by the labors of the industrious polypi. To illustrate these phases of development, Part I describes the Physiography of the Archipelago, alluding both to the original growth and the later imperfect stocking of the islands with plants and animals. It has been convenient also to state here other geological facts more or less intimately connected with this history.

The high islands have been built up above the sea-level by the subaerial accumulation of basalt. When the igneous action ceased, the lengths of the subsequent periods are measured by the amount of erosion effected. If the time has been long, the canyons excavated by the running streams will be numerous and deep: if the time has been brief, the erosion produced has been correspondingly slight. Hence it is possible to speak of the "Old" and the "New" topography.

Our studies especially illustrate the peculiarities of the Hawaiian type of volcanic action: mostly quiet, partly explosive, discharging the surplus material in surface flows, but more usually as a break-down into unknown interior abysses. The secret of the fluidity is found in the easy fusibility of the rock.

It is hoped that this treatise will contribute materially to the solution of the Volcanic Problem. A deep-seated source of the heat seems to be required, which acts upon water, converting it into super-heated steam. Whether this moisture comes chiefly from surface streams, the ocean, or from the original interior magma of the earth is not so clear; but its effect in urging liquid material upward cannot be questioned. Our efforts are rewarded by the abundant demonstration of this upward pressure. How far this same energy will explain tectonic earthquakes and the secular elevation of large terrestrial areas is likewise a matter for further reflection.

The public are indebted to the Hawaiian Gazette Company, Ltd., for its liberality in providing the means for the issuance of this volume. Eastern people are not aware of the existence, upon what are sometimes imagined to be "cannibal islands," of such an extensive plant for the speedy manufacture of pamphlets, books and newspapers, with first-class illustrations, as is maintained by this Company. While the title intimates a subject of local interest, scientists will find that the facts presented are an important factor in the discussion of world-wide igneous problems; and tourists can add their quota of observations to those recorded, for it is true that Kilauea is never precisely the same in any two successive days.

The author takes this opportunity to thank the many gentlemen who have freely assisted him in the attempt to elicit correct statements and to eliminate everything that is trivial or untrustworthy.

CHARLES H. HITCHCOCK.

Honolulu, T. H., May 3, 1909.

PART I.

Physiography of the Hawaiian Archipelago.

The Hawaiian Archipelago, "the loveliest fleet of islands anchored in any ocean," is usually described as consisting of eight high inhabited islands with a N. W., S. E. trend. The nautical charts, however, show a dozen smaller low islands and shoals situated to the northwest of the more important part of the group, over which the authority of the territorial government is now extended. The archipelago extends over twenty-five degrees of longitude, or about 1,800 miles. The following table presents their names, order, areas and extreme altitudes:

LOW ISLANDS AND REEFS.

Ocean Islands	10 feet
Midway Islands	57 "
Gambia Shoal	..
Pearl and Hermes Reefs	..
Lisiansky Island	50 "
Laysan Island	25 "
Maro Reef	..
Dowsett's Reef	..

THE LOWEST OF THE HIGH ISLANDS.

Gardiner Island	170 "
French Frigate Shoal	120 "
Necker Island	300 "
Frost Shoal	..
Nihoa or Bird Island	903 "

HIGH INHABITED ISLANDS.

			Area in Square Miles
Niihau		1,300 feet	97
Cinder cones adjoining, named Kaula and Lehua.			
Kauai	Waialeale	5,250 "	547
Oahu	Kaala	4,030 "	598
Molokai	Komokoa	4,958 "	261
Lanai		3,400 "	139
Maui	Haleakala	10,032 "	728
Kahoolawe	Moaulu Hill	1,472 "	69
Hawaii	Mauna Kea	13,825 "	4,015

The uninhabited islands have an area estimated at six square miles, making the total of 6,460.

These islands are partly those termed low and those called high. The first may be swept by the ocean waves in times of storms or may be simply reefs or shoals. Their origin may have been the same as that of the high islands which are supposed to have been igneous protrusions from the bottom of the ocean. The low islands may be capped by coral growth which commenced existence after the igneous eruptions had ceased. This archipelago may be conveniently divided into first, the low islands and shoals, secondly the high islands below 1,000 feet in altitude above the sea level, and third those that exceed 1,000 feet above the sea with their satellites.

The depth of the ocean adjacent is put from 16,000 to 18,000 feet as determined by soundings. Adding to these figures the elevations of the highest volcanoes on Hawaii, we have the evidence of the existence of volcanoes 30,000 feet high. If arranged on a line, the islands of this archipelago represent a row of conical peaks from 18,000 to 30,000 feet.

These cones must be very blunt, with a base of say two degrees upon each side, or four degrees for 16,000 feet altitude, which would represent an incline of about one hundred and fifteen feet to the mile. This corresponds with the existing visible slope of Mauna Loa. This slope is so gradual that one can hardly realize that the mountain is nearly 14,000 feet high, when viewed from a distance of thirty miles; and the suggestion that the steep needles or islands might be overturned by earthquakes is surely unfounded. These islands are not arranged upon a single line, and the soundings prove that other cones are scattered indiscriminately about the archipelago which do not reach the surface of the water. The submarine area adjacent to these islands must be very extensive, so much so as to suggest the existence of Tertiary strata through which the volcanoes have eaten their way.

Many authors believe that Ocean islands represent the first of these volcanoes to commence eruption, followed by the rest of the first group and by the higher islands successively. Kilauea is the last because that is now an active volcano, and should another grand volcanic display be manifested in the future, it will be located to the southeast of Hawaii. This theory is probably correct in the general way; supplementary details may be suggested by the descriptions in Oahu, Maui and Hawaii.

The charts published by the Hydrographic Office of the Navy Department of the most remote low islands of the Hawaiian Archipelago were prepared from observations made by the officers

of the U. S. steamer Lackawanna in 1867.[1] The others have been explored by European navigators. This series is extensively used by mariners in the mid-Pacific, and the sailing directions are being constantly perfected, chiefly by the Navy Department of the United States.

In 1899 the U. S. S. Nero, under the direction of Lieut. Commander H. M. Hodges, was fitted up with the necessary apparatus to take soundings, observe the temperatures and the character of the sea bottom between Honolulu and the Philippines by the way of Guam, and this was for the determination of the proper route for a telegraphic cable. I will mention the principal matters of interest ascertained along this line between Honolulu and Midway, where a cable office has been established.

The route lay on the eastern side of the archipelago, a distance of 1,184 miles. Leaving Oahu the depth increased quite rapidly until it reached 2,500 fathoms, at a distance due north of thirty miles. The line led along a plain from 2,500 to 3,000 fathoms in depth, save that there were two or three outlying peaks rising half-way or more to the surface. The average temperature of the surface water was 73.2° Fah.; of the bottom about 35°.

The pelagic deposits were chiefly Red clay, Volcanic mud and Globigerina ooze. The first is the most extensive, being a smooth, sticky mud, from light yellowish brown to dark chocolate in color, and composed of clay, calcareous and siliceous organisms, mineral fragments of volcanic origin, and various products of local chemical formation, as nodules of manganese peroxide, crystals of phillipsite and particles of palagonite. The teeth of sharks and fish were not found in this section. The least depth at which the red clay was found was 2,010 fathoms. This material is supposed to have been derived largely from the pumice blown out from volcanoes and carried over all the oceans by currents. When thoroughly soaked it sinks and changes its color.

The volcanic mud consists of pumice, glass, ashes and the debris of volcanic rocks, more or less mixed with organisms at great depths. It has been derived from the volcanic masses of the several islands adjacent, and thus passes into the terrigenous deposits. The most abundant constituent is the glass, occurring as threads, masses from which the fibres were drawn out and angular transparent fragments. Red palagonite is more common in this than in any other pelagic deposit.

The Globigerina ooze contains over 30 per cent. of calcium carbonate in the form of minute shells of foraminifera, of which

[1] **Senate Documents, 40th Congress, 2d Session, Ex. Doc. No. 79.**

the most common is that from which the name is given. The animals swarm in the waters above 2,200 fathoms and the dead shells accumulate at the bottom of the sea. Some idea of their appearance may be learned by inspecting Plate 1A, showing the cast shells considerably magnified. When alive the surface of the sphere is covered by numerous spines suggestive of chestnut burrs, except that they are of very uneven lengths. When this ooze is brought to the surface and is solidified, it becomes chalk.

No one can satisfactorily estimate the thickness of these pelagic deposits. They must have been accumulating for several geological periods. Because of the presence of large amounts of calcium carbonate in the ocean of organic origin, the water has dissolved as much of that mineral as it will carry and also abounds in carbonic acid, which assists in dissolving other substances than calcium.

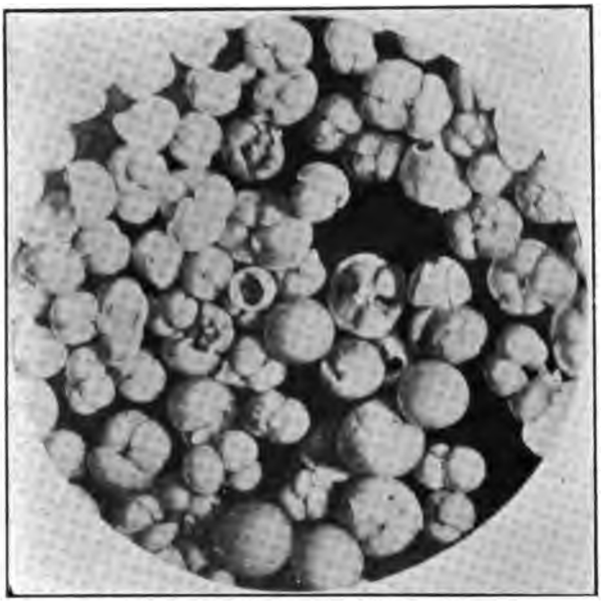
Certain other deposits common in other parts of the ocean—as the Diatom and Radiolarian oozes and the Blue and Green muds—are wanting in the materials brought up from the bottom along the line between Honolulu and Midway.

THE LOW ISLANDS.

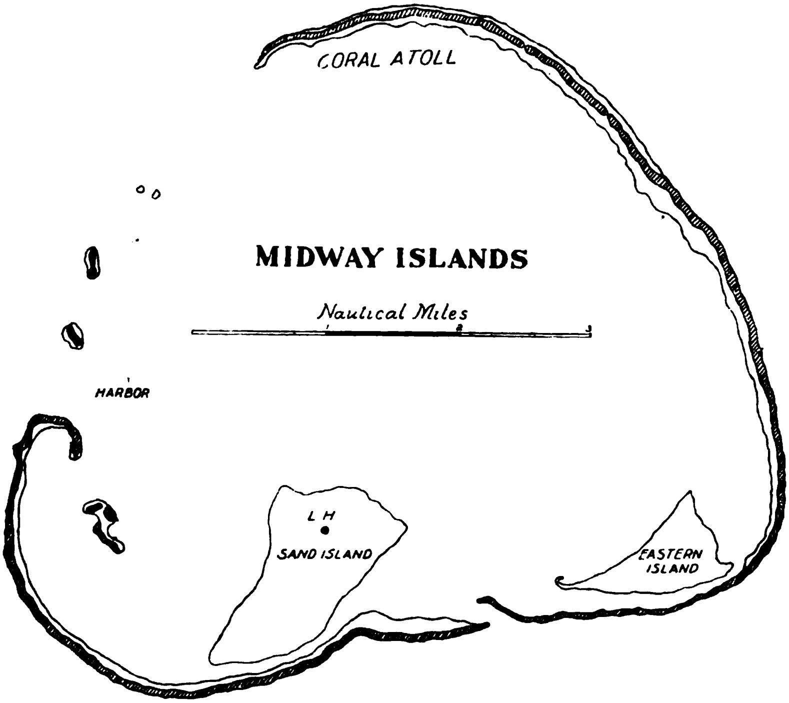
The Ocean Islands are the most remote of the group, touching longitude 178° 30′, being very nearly the antipodes of Greenwich. It is a small sandy area about one mile square inside of and nearly touching the coralline rim of about sixteen miles circuit. On the west side there is a gap of a mile, but the water is too shallow at the entrance and the interior to permit of the ingress of seagoing vessels. The area must be about thirty-eight square miles. Another name is Curé; also the inside island is called Green. The shrubbery is better developed than upon Midway. There are also inconspicuous bare, sandy islands in the lagoon, ten feet in height. Upon the "Sand Island" the Lackawanna party found the trunk and roots of a large tree, probably coniferous, drifted from the American continent. Both Ocean and Midway Islands afford convenient conditions for the establishment of rookeries by numerous albatross, tropic birds, man-of-war hawks and gulls, and a few curlew and plover. Turtle, seal and fish also abounded.

The Midway Islands closely resemble the Ocean. There are the same two kinds, the one shrubby and the other sandy, with a larger coralline rim. Originally they were called Brooks Islands, from their discoverer, Captain N. C. Brooks of the Hawaiian bark Gambia, in 1859. The coral rim is eighteen miles in circuit,

PLATE 1.



A. Globigerina Ooze. x 15



B. Map of Midway Islands.

with a gap of four miles upon the west side, where several breakers remain. The rim is a compact coral wall, five feet high, and from six to twenty feet in width. The entrance to the harbor is about a mile wide, with a depth of three fathoms. To the north of the two islands is a lagoon from four to eight fathoms in depth, connected with the harbor by shallow water a mile wide. The total area of the atoll is about forty square miles. The most important feature is the presence of two islands within the rim, named Sand and Eastern. The one composed of sand adjoins the harbor, one and a half miles long, three-quarters of a mile wide, chiefly composed of broken coral, shells and sand, and reaches an altitude of fifty-seven feet. Occasional clumps of shrubs and a few patches of grass were to be seen at the first, but must now have partly disappeared since its occupation as a cable station. The other island nearly touches the outer rim, is one and a quarter miles long, one-half mile wide, of uniform elevation from six to fifteen feet, covered with small shrubs, a few vines and coarse grass. The beach is of dazzling brightness. Water is found at the depth of four to seven feet upon both islands, which is free from organic impurities, but contains enough lime to place it in the category of "hard water," besides more than the average content of salt than is seen upon the upland. Considerable labor has been expended in the erection of the buildings necessary for a cable station and the improvement of the harbor. It was first occupied for this purpose in 1902.

There are four or five main buildings of reinforced concrete consisting of the plant necessary for the cable service, the house of the superintendent, the quarters for the staff, apartments for general use, and buildings for employees. Everything necessary for the comfort of the men living in such an isolated locality is abundantly supplied by the Cable Company. Plate 1B is a map of the several Midway Islands from the latest Government surveys. The large ring is a typical coral atoll with a harbor upon the west side and deeper water in the central part than near the outside. Except the larger Sand Island the other islets may be swept by the ocean when the unusual storms prevail.

In 1885 a sixty ton schooner, Captain Bohn, left Yokohama in August and was driven far away from its course by storms, and reached Midway Island in November considerably damaged. There were twenty-seven persons aboard, and they remained here till March 8, 1886, the island furnishing plenty of food, as was said, enough for a three years cruise. The drifted logs must have furnished material for the needed repairs to the schooner. The

vessel landed at Niihau May 12th, and reached Honolulu May 24th.

Later the Wandering Minstrel, Captain Walker, was wrecked during a heavy gale; and its occupants compelled to live upon birds' eggs and fish for sixteen months. In 1906 the Mongolia ran aground upon the sand, but was fortunately hauled into deeper water in a few days without serious injury.

The Pearl and Hermes reef is bounded on the east, south and west by a coral rim like that of the Midway Islands atoll, while on the northwest side instead of a continuous parapet it consists of detached rocks. Its area is certainly double that of Midway. There are two small sand islands near each extremity. The circumference of the reef is forty-two miles; the shape is irregular, the longer diameter, east and west, being sixteen miles, and the meridional from north to south nine and a half miles. The examination of this atoll was very much hurried.

Lisiansky Island was examined by Captain Lisiansky of the Russian Navy. It is surrounded by shallow water for six or seven miles. It deepens to ten or eleven fathoms at the end of the first mile; to fifteen the second and to twenty-five at the distance of six or seven miles. Eventually the slope deepens to a declivity of forty or fifty degrees.[2]

In 1905 a party of Japanese bird poachers spent several weeks here, according to the Hawaiian papers, and killed 300,000 birds for their skins. They were captured by the U. S. Revenue cutter Thetis and brought before the courts.

An enterprising wrecker went to the French Frigate Shoals about the same time and obtained several thousand dollars worth of booty from an abandoned French bark. It was said that they would probably visit Lisiansky Island in search of the confiscated bird skins.

Laysan Island is noted for its birds and the deposits of guano. Quite recently it was visited by the U. S. S. Albatross sailing in the interest of the Department of Fish and Fisheries. The naturalists of that expedition spent a week in studying the fauna and flora of this island. It has an area of three and one-half square miles, consisting of white coral sand with some shrubs. Birds are everywhere and so fearless of men that they must actually be pushed aside by one's feet. They consist of albatross, terns, tropic birds, gannets, duck, curlew, plover, rail, finch, honey eater and sparrows. Professor Nutting estimated the number of birds

[2] A voyage around the world in the years 1803-6. By Urey Lisiansky. quarto, London; 1814.

PLATE 2.

Birds of Laysan Island.

seen upon the islands as six to eight millions, of which the terns are the most numerous, followed by the albatross, two millions. It is the breeding place of these creatures, a rookery. Allowing half a pound of fish for food to each albatross, they must consume five hundred tons daily. The eggs are laid in late January or early February, and the young are equipped with adult plumage and ability to take long flight by the end of September. For ten months of the year these birds live at Laysan, not wandering far from their breeding ground.

"Much of interest could be said concerning the guano deposits and the operations of the company that lease the island. Thousands of tons are exported annually, and it is entirely possible that this valuable fertilizer is now being deposited as rapidly as ever it was, owing to the wise policy of not disturbing the birds that is rigidly enforced by the company. The excrement is almost entirely fluid, and gradually saturates and fills the thin soil and porous coral rock, thus making the 'guano' of commerce. Strangely enough, there is no very perceptible odor, even at the rookery.

"The naturalists of the Albatross spent a week in studying the fauna and flora of this exceedingly interesting island, while the naval officers made a complete map, including a chart of the reefs near the anchorage. Here are found unexcelled conditions for collecting and studying the life histories of birds. All the species are very abundant and can be seen in a day's visit. Every species can be caught, either in the hand or with a hand net, and mercifully killed with chloroform without mutilation or blood stains. They can all be studied at leisure, and at close range. The photographer finds himself in a veritable paradise, able to set up his camera at any desirable distance, even to 'pose' his subjects to suit his fancy, and take pictures of birds' nests and young to his heart's content.

"It is simply delightful to find one spot at least in this world of ours where the birds are not afraid. So long as the guano holds out those conditions will probably remain unchanged. If this time comes to an end, the Government should see to it that this wonderful preserve of avian life is protected from the ravages of man, the destroyer, and of the rapidly diminishing moiety of his better half that still persists in the aboriginal feather-wearing habit." [8]

Thousands of eggs are gathered here from time to time which are used in the manufacture of albumen.

[8] C. C. Nutting, in Popular Science Monthly, Vol. LXIII.

One of the closing acts of President Roosevelt's administration was the setting apart of eight islands of the archipelago as a reservation for the protection of the native birds, as here shown:

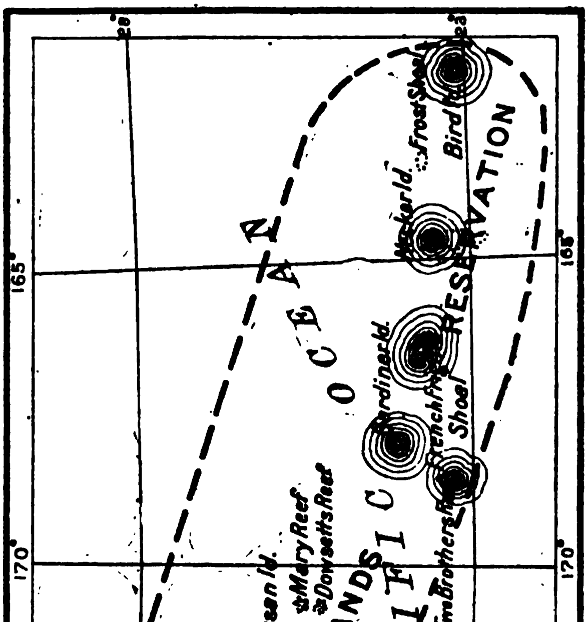


PLATE 4.

A. French Frigate Shoals.

Island, south side.

THE LOWEST OF THE HIGH ISLANDS.

Gardiner Island is a cone one hundred and seventy feet high, one and one-half miles in diameter. At the base there is a cliff encircling the island, sixty or seventy feet high, made by the dashing of the waves against the rock. On the east side there is an additional small mass of land.

French Frigate Shoal is shaped somewhat like one's boot. There are five sand spits, always dry, near the northern end. The enclosed area is full of rocks and banks mostly submerged and separated by deep holes. The largest islet, Plate 4A, is a basaltic rock one hundred and twenty feet high, and is situated on the inside of the reef less than three miles distant. The area of the shoal is from twenty-five to thirty square miles. The water is seventy-two feet deep a short distance away from the rock.

The Maro Reef is of quadrangular shape about twenty-two and five-tenths square miles in extent. There is nothing visible but breakers, which are very low and the reef is a most dangerous one for the mariner to encounter.

Necker Island has much the same shape as the French Frigate Shoal. The highest peak is three hundred feet high. The island is seven-tenths of a mile long, bounded by the usual cliff made by the waves. The widest part is five hundred feet. The top is undulating, with some soil. There seems to be a landing place on the inner angle of the foot. Quite an extensive shoal surrounds the island, represented by one authority as being principally upon the south side. Necker Island is surrounded by shallow water, eighty-four feet deep at the distance of one mile from the shore. Plate 4B shows the south side of the island.

NIHOA OR BIRD ISLAND.

Our information about this island is derived from two reports made by Dr. S. E. Bishop in connection with a large excursion party from Honolulu, July 20-22, 1885. The Princess Liliuokalani, afterwards the Queen, took the direction of affairs. The party numbered between two and three hundred people, including Dr. Bishop as surveyor and geologist, Hon. S. B. Dole ornithologist, James Williams photographer. Landing was effected with some difficulty and because the sea rose during the forenoon it was less easy to reëmbark in the small boats carrying the people and their effects to the steamer. The island was densely crowded with the nests of birds estimated to be 2,500 to the acre, which would make half a million nests and twice as many birds. Being disturbed by the visitors, the adult birds rose in enormous clouds, leaving

their eggs and young, usually a single one in each nest. Surveying was carried on industriously till all at once a fire broke out, and because the surface was covered with dry grass and twigs a dense smoke arose rendering it impossible to take observations, and everybody scrambled back to the steamer. The island is very like the rocks in other regions which furnish guano, and doubtless is capable of furnishing a considerable amount of fertilizing materials.

Though his observations were interrupted by the fire, Dr. Bishop has described succinctly the main features of the geology and topography. He says:

"The extreme length of Nihoa from W.N.W. to E.S.E. is not far from 5,200 feet. Its average width is about 2,000 feet, giving an area of about two hundred and fifty acres. Four-fifths of this is a very steep grassy slope, the rest precipices. I did not see enough level ground to build a native hut upon without terracing. The general contours are much like those of Punchbowl towards Waikiki, save that the ridges tend inward instead of radiating outward."

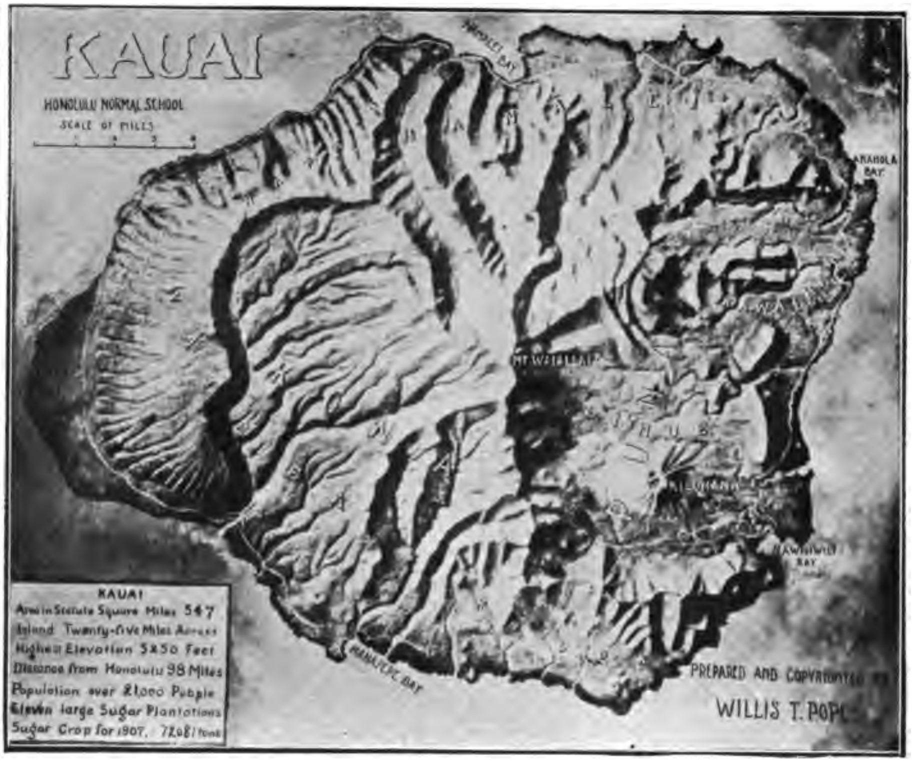
The N.E. pinnacle, which overhangs, is eight hundred and sixty-nine feet high; the higher N.W. pinnacle is nine hundred feet; both subject to correction for from ten to twenty feet. As to the geology, Nihoa is the small remaining portion of an extremely eroded and deeply submerged volcanic dome homologous with the larger islands which still survive in their various stages of present upbuilding, recent extinction of volcanic activity, less or more advanced erosion, and slighter or deeper subsidence. Nihoa was probably a more ancient crater than Kauai. It seems to be a pair of clinkery pinnacles out of the inner core of a once mighty dome which has been eaten down by winds and rains for thousands of feet and during unreckoned ages.

Several parallel basaltic dikes cut the island from end to end and from summit to base, perhaps forty or fifty in number. Dr. Bishop infers from the great number of these dikes a very protracted period of igneous activity. The island may have been like Oahu or Maui originally, losing its substance partly by erosion and partly by submergence till only a small remnant is left.

THE HIGH INHABITED ISLANDS.

The first of the inhabited islands met with in proceeding southeasterly is Niihau, fifteen miles west of Kauai. It is eighteen miles long, eight miles in its widest part, and has an area of ninety-seven square miles. There seems to be a central high por-

PLATE 5.



Relief Map of Kauai.

tion called Kaeo and a lower plain on three sides. The higher part is irregular, destitute of sharp peaks and narrow ridges. The side towards Kauai is precipitous. About two-thirds of the island is comparatively low, of coral origin, and is the region that is inhabited.

The map shows quite a large pond to the south of Kaeo, and smaller ponds and artificial reservoirs in other sections. The little island has had a rather romantic history. It has now been owned for forty years past by Mr. George S. Gay. The family includes Mr. and Mrs. Gay and several children, who except for an occasional guest, seldon saw any of their own race previous to our occupancy of the group. Mr. Gay made a comfortable fortune on the island, of which he was the sole owner. The island is a great sheep ranch, embracing about 70,000 acres, with a native population of 178, all that remains of nearly 1,000 natives who inhabited it sixty years ago.

It would seem that here, if anywhere, the conditions were favorable for the perpetuity of the native race. Mr. Gay did everything in his power to preserve the aborigines from the evils attendant upon civilization; but in spite of his efforts they have been rapidly dying out, just as their brethren in all other parts of the island group have been dwindling away.

There are two small cinder cones adjacent to Niihau, Kaula upon the east and Lehua upon the west side. The first is about the size and shape of Punchbowl cut in two, and the lower half destroyed by waves. The concentric structure of the yellow cinders, much like the surface of the lower Koko Head, is very obvious. Lehua proves to be a similar remnant, less eroded, as it has maintained about two hundred degrees of its circumference instead of the one hundred and forty degrees of Kaula. Both these crater cones have the western or leeward sides the highest, because the trade winds drive the falling rain of ashes and lapilli in the direction of the air movement, building up a compact laminated pile of material to the leeward. The subsequent erosion by the waves will fashion a crescent shaped island opening to the winds and surges upon the northeast side.

KAUAI.

Kauai is the "Garden Island" of the archipelago because the rocks have been disintegrated into soils more effectually than elsewhere. The relief map by W. T. Pope of the Normal School has been reduced in the photograph to about one-fifth of its original dimensions, Plate 5, and shows well the principal physio-

graphic features. The shape is between circular and quadrangular, over twenty-five miles in diameter, with an extension of swampy and low marine ground upon the west side. No very extensive explorations have been made, but we have the statement by Professor J. D. Dana in the Report of the United States Exploring Expedition, 1840, that the layers of basalt are thicker in the center and dip outwardly toward the sea in all directions. Waialeale is the highest point in the island, 5,250 feet, obtusely pointed, covered by bogs, wet most of the time and very rarely visited, certainly by no scientific person, so far as the records go. The principal streams start from near the summit: three of them entering Hanalei Bay upon the north, one flowing on the east through Lihue, two to the south. The McBryde Sugar Plantation derives power for its operations from an artificial waterfall upon the Wainiha stream only one and a half miles from Hanalei Bay. The water is taken from the stream at an elevation of seven hundred feet, is carried in a ditch for four and one-half miles, and falls five hundred and sixty-five feet to the wheels. The power is conveyed by a pole-line for thirty-four miles over rough mountain ranges considerably to the east of the Wainiha to the mill.

Hanalei Bay upon the north shore seems to be a drowned valley, as the intervale extends miles up the stream, like the broad low plains near the mouths of large streams in more northern latitudes. On the opposite shore is the Hanapepe valley entering a bay in a similar manner, and is spoken of as one of the most extensive and beautiful upon the island. Nawilili Bay upon the southeast is the principal landing place for visitors from Oahu, and it seems to skirt the edge of a plateau two hundred or three hundred feet high. The Wailua River has a noted cataract upon it two and a half miles from the sea. The smaller streams are generally nearly closed by bars of coral sand.

The distinction between the windward and leeward sides is very plain, as made known by the erosion. It is emphasized upon the Government map by the primary division into the two districts of Puna and Kona. Lihue, Kawaihau and Hanalei show a greater amount of denudation than the slopes of Waimea, and in this last region the contrast in the amount of excavation is very great between the two sides of the Waimea River, the west side being a cliff and the east a gradual slope from the dividing range seven or eight miles distant. There must be a small wind-gap where the road from Hanalei passes over the divide to the Waimea, whose altitude is 4,525 feet and bears the name of Kilohana. Sugar plantations adjoin the coast on every side except the northwest,

Napali, where cliffs from one to two thousand feet high constitute the shore line.

Between Nawilili and Anahola Bays there is an extensive plain from two hundred to three hundred feet high cut down through soft material forming canyons for the rivers. The earlier authors ascribed this material to the decay of the basalts, which came from ancient volcanoes in the interior. Many of the layers seem to be the result of decay, as they are filled with the concentric boulder-like masses somewhat related to the columnar structure; but inter-bedded with them are layers of earth better comparable with volcanic ashes which may also cover the surface. It is not strange that ashes should present the slight inclinations of from one to five degrees commonly noted here. The relief map shows in Lihue one large volcanic cone, Kilohana, nearly a mile in diameter, and other smaller ones. Why have not those plains been made up of the ejections from the several secondary volcanoes, like alluvial fans, rather than from the older ones discharging lava? The prevalence of volcanic ashes has been proved for the active and extinct vents in Hawaii and Oahu, and should surely be looked for upon any of the other islands. Their recency would seem to be proved by the steep walls of the canyons in the loose materials. There would therefore seem to be two classes of volcanic discharges in Kauai, first the underlying basalts making up the great dome of Waialaele, and second many secondary craters, situated upon the flanks and eroded basins of the earlier lavas, and representing an inferior degree of activity.

Crossing the Wailua River is a ridge several hundred feet high less than a mile back from the shore, rising abruptly above the plain. This would naturally represent one of the older lavas. Back of Anahola a similar wall is pointed out, where a hole has been worn through the hill.

Professor Dana suggests the possibility of the presence of a second principal dome to account for the greater elevation of the land in Napali on the shore opposite to Niihau. The two islands have cliffs in a line with each other. If we could imagine some volcanic disturbance of a late date that should fracture the ledges, we could readily understand how the debris should have disappeared later by the action of the waves. Granting the presence of a dome between the islands the structure would simulate that of Oahu and Maui where two eruptive mountains have been connected by necks of later-formed material.

In Koloa there are several secondary volcanic cones in an area of eight or ten square miles. The lavas are black with the pecu-

liar ropy structure and beneath are caverns, either the result of bulging or left by the streams that were protected by the congealed surface. Unlike those back of Hilo, they do not show any stalactites; but being near the sea the waves of the ocean press into the cavities and spout from orifices quite high into the air. In this neighborhood are the celebrated barking sands, as well as at Mana at the extreme western end of the island. Some of the soils are intensely red in color because the growth of the vegetation brings the iron into new combinations with organic acids.

The shores of Kauai are lined with coral reefs and limestones, which are disintegrated and washed into beaches, and may be blown inland considerable distances. Some of these wind-driven sands reach altitudes of thirty-five and fifty feet and become consolidated. It is difficult to draw the line between the wind-blown sands and beaches formed by elevation of the land, both of which undoubtedly are to be found here as on Oahu.

A confirmation of our belief in the greater antiquity of Kauai over the other islands is derived from the study of the plants. This is presented forcibly by Dr. William Hillebrand in his Flora of the Hawaiian Islands. Taking the extremes, it may be stated that the flora of Mauna Loa is the poorest and most uniform, and that of Kauai the richest and most individualized in species. On the whole the intervening islands follow the same ratio when allowance is made for differences and elevation.

"The monotony of the forests of Puna, Kau and South Kona on Hawaii, will strike every attentive visitor and disappoint the botanical collector by the scarcity of the harvest. This can hardly be ascribed to the periodical destruction of forests by lava streams, for these follow with long intermission, affect only limited areas at a time, descend mostly down the northeast slope, and it is surprising to see how quickly the ruin is repaired, how speedily decomposition takes place in the lava when exposed to the influence of copious rains and the trade winds. In 1862 I visited the lower end of the lava stream which in 1856 had cut its way through the forests toward Hilo. A belt of thirty feet in width on each side of it was covered with a shrubby vegetation which had already attained a height of three to four feet. In the break of the *pali* of Oahu at the head of Nuuanu valley, through which the trade winds sweep with intense force nearly the entire year, one could observe hard compact basalt gradually softening until it could be cut with a pocket knife. And with how little soil plants are content when favored by copious rains is exemplified by the fact that the natives of Puna, Hawaii, raise good crops of sweet potatoes in the hollows and cracks of bare lava by simply covering the bud-

ding sprigs with decayed leaves and herbs. In the same region I once saw a cocoanut lying on smooth *pahoehoe* lava which had germinated there and sent off a root for a distance of eight inches until it met a crack down which it descended. On the other hand, the same kind of lava when not affected by rain and wind will remain unchanged for centuries, as may be seen under the lee of East Maui. Nowhere else have the forests, although extensive, so gregarious a character as within the area of Mauna Loa, and the species which comprise them show hardly any variation from those forms which are met with more to the east. The forests of Hilo and Hamakua, which belong to the region of Mauna Kea, are already more diversified, and still more those of the Kohala range.

In great contrast stands the vegetation both of Kauai and of the Kaala range of Oahu. Most of Mann's and Wawra's new species come from Kauai, and Mr. Knudsen's collections have added still more to them. Even the species which that island has in common with others generally vary from them in one or more particulars. The Kauai species of the leading Hawaiian genera are in all instances the most specialized, to be distinguished by more striking characters than the others. Examples are: *Schiedea, Raillardia, Dabantia, Campylotheca, Lipochaeta, Pittosporum, Pelea.* The proportion of species peculiar to Kauai with species peculiar to all the other islands is about 67:382, or 17.5:100."

Much may be learned from a study of the origin of the plants of the archipelago. Out of a thousand species, as described by Hillebrand, there are five hundred and forty-seven exogens, thirty-five endogens and eighty-four vascular cryptogams,, chiefly ferns; of an exclusively Hawaiian origin, sixty-six per cent. Of the remainder there are first, many tropical species widely distributed throughout Polynesia; second, many that are allied to North American forms; third, a smaller number resembling plants in Asia and Polynesia; fourth and fifth, the smallest numbers, from Australia and Africa. The plants useful for food or fabrics have probably been introduced by the natives. They are such as the plantain, banana, coconut, breadfruit, pineapple, yam, taro, cotton, peach, fig, sugar cane, orange and alligator pear. Various weeds, mostly undesirable or noxious, particularly the lantana, have come with American immigrants. A few characteristic indigenous Hawaiian plants are the koa wood, lately called Hawaiian mahogany, the hau and milo, malvaceous species, silver sword and the ohelo, a huckleberry of the size and often color of the cranberry. Some plants become shrubs or trees, as the lobelia, violet and many Compositae. All the plants are either exotic or

else have been derived from species brought by the waves, by animals or by man.

A good illustration of the origin of the vegetation is the screw pine, pandanus or lauhala. This is a small tree growing at the sea shore. The seeds are edible and are gathered together in bunches somewhat like a small pineapple, each one being a wedge with the small part inside. These seeds will stand saturation in water for months without losing their vitality. Hence they may be carried hundreds or thousands of miles from the place of their nativity, and when washed inland by unusually high waves will be placed where they will sprout and grow up. I once saw a place in Kauai where hundreds of young lauhalas had started to grow near the sea shore just like the multitude of young maples in New England. In both cases the majority die, but some will live, and upon the islands the lauhala will be the means of the increase of dry land.

There is no tree with a wider range in the Pacific than the pandanus. And it was in existence in the Triassic period in Europe. It is therefore one of the oldest and most persistent of plants, and the one best fitted to start plant life upon the isolated volcanic islands for the first time peering above the waters.

The accepted doctrine for the covering of the islands of the Pacific with vegetation is not that they were specially created where now found, nor that they are tips of a submerged continent, but that the barren rocks attracted the seeds brought by ocean currents from all sides, and that when the plants in the new region found the conditions favorable for a luxuriant growth they flourished exuberantly and developed into the new species said to be indigenous. And the various examples just cited prove that there is a constant development both of vegetable and animal life in the new habitats.

Oahu has been celebrated for the abundance of the peculiar land shells known as *Achatinellidae* or agate shells living naturally upon it. There are over two hundred species of them, represented by 800 or 1,000 varieties, and each of these forms is confined to a small section of territory in the forests of the two ranges of mountains. Each valley has its own peculiar varieties. The most widely divergent forms of one group will be found in the valleys that are most distant from each other, while intermediate varieties will be found in the intermediate valleys. The species living far apart cannot be connected by minute gradations without bringing in some of the forms found in the intermediate territory.

Granting that these organisms are all descended from one ori-

PLATE 6.

Relief Map of Oahu.

ginal stock, the diversity at present existing has been supposed to be produced by exposure to different environments, coöperating with a series of isolations; and if the diversities have been systematically developed it must be possible to locate the home of the original species and the routes of their migrations. It will be interesting also to discover whether some one of the islands carried the original animal, whose descendants migrated to other parts of the archipelago, and whether the developments have corresponded to the geological ages of the different areas. While no one has yet succeeded in discovering the order of development, there is a suggestion that the ancestor of the Oahu forms came from Kauai—and it is a fact that these creatures are very scarce upon Hawaii. This order would correspond to that already mentioned about the plants, and so far forth both are in agreement with the geological conclusions.

OAHU.

The geology of Oahu has been set forth quite fully in two papers by the author in the Bulletin of the Geological Society of America, 1900 and 1906, The Geology of Oahu, and Diamond Head. The annexed photograph of the relief map, Plate 6, shows admirably the general features of the topography, two parallel ranges of mountains separated by an intervening valley and both the elevated lines considerably eroded by streams of running water. The range on the southwest side is called Kaala or Waianae, culminating at 4,030 feet, with a dozen separate peaks, and the deepest part is near the middle, over which a road has been built reaching the altitude of 1,590 feet. On the ocean side there are five prominent ridges dividing the general slope into six valleys, the largest of which, holding the village of Waianae, measures six miles from the crest to the sea and is about three and one-half miles wide. Each valley has been excavated by running streams, and the erosion has been greatest upon the slope facing the water, though there may be others of equally large dimensions now concealed by later flows It is evident that the Kaala area represents the original island: igneous discharges produced a dome bordered by marine strata and traversed by subsequent injections. Later the copious rains brought both by the trade wind and the Kona storms channeled out deep valleys upon both sides. This island existed for many ages before another larger volcanic mass was developed in the Koolau range, and when the uppermost igneous sheets were in motion, the corrugated eastern border of Kaala was covered by the advancing lavas. This fact was first observed by Professor J. D. Dana and

is illustrated by a photograph, Plate 7, by Roger Sprague. Kaala is easily recognized by its greater height, and the plain consists of the later basalts that flowed westerly from Koolau. The view is taken from near the summit of the lowland, or the divide between Pearl City and Waialua, at Wahiawa. The plain consists of soft material rendered plastic by the decay of the originally hard basalts. The structure is obvious when one examines the sides of the canyons.

The Koolau range is divided into two parts, the more northern Koolauloa fifteen miles long, and the more southern Koolaupoko twenty-two miles long. The most pronounced ravines on the west side are upon Koolaupoko. At first, because of the lack of information, it was supposed that ravines were rare in the northern section, but Plate 6 shows that valleys are well developed all along the western slope. The highest of the Koolauloa peaks reaches 2,360 feet.

Koolaupoko has several peaks that are higher. Beginning at the north end is one not named, 2,800 feet, at the head of Halawa valley. Lanihuli on the north side of the only road crossing the range at the Pali is 2,778 feet, and Konahuanui on the south side is 3,108 feet. Farther southeast the crest of the mountains runs more easterly, terminating in a cliff six hundred and forty-two feet high at Makapuu point. The eastern slope has been greatly eroded by the rains connected with the trade winds. Two subordinate ridges enclose Kaneohe Bay, the more northern, Kualoa, being opposite the meeting of Koolauloa and Koolaupoko, and the more southern extending from Konahuanui to Kaneohe point. The greater size of this valley seems to be due to a concentration of the erosive agencies, seen also in the excavation of the wind gap pali 1,207 feet, and the nearest approach to it of a second gap at Kalihi perhaps 200 feet higher. A third gap is in the Koukonahua gulch leading up from Wahiawa. Olamano is an isolated peak, needle-shaped, 1,693 feet, practically inaccessible. It is a relic of the former general slope to the sea from Konahuanui. At the Pali is a cliff about a thousand feet high, celebrated in history as the scene of a catastrophe, when a victorious army forced its adversary to fall over the steep slope and lose their lives. The word *pali* is Hawaiian for a precipice.

When viewed from the east the precipice at the Pali is seen to be corrugated like the ribs of a domestic washboard. Plate 8 represents a corresponding cliff on the west side of Kaala. The visible part of the cliff must be about 2,000 feet high, and at its base is situated the plantation of the Makala Coffee Company. Like the related steep escarpement of the Arizona province the

PLATE 7.

Kaala from the east.

Kaala from the southwest.

recession is precipitous, but here there are added numerous valleys rendering the whole surface corrugated.

The deeply eroded flanks of Koolauloa and Koolaupoko finely illustrate the modern doctrines of subaerial erosion.

GEOMORPHY.

Within these two mountainous areas, the foundation rock everywhere is basalt, disposed in layers dipping quaquaversally from the central lines. Kaala was an elliptic, Koolau an elongated dome, each with its seaward sides sharply incised by canyons, and both joined together by a later formed plateau, sloping both northerly and southerly. Dana calls Oahu a "volcanic doublet," the united work of two great volcanoes which have been so greatly eroded that the proper position of their craters is now conjectural. This view is confirmed by a comparison with the Island of Maui, where one of the volcanic masses has suffered but slightly from erosion and the connecting plain is nearly at the sea level. Assuming that there were originally two volcanic domes, with layers dipping outwardly some five degrees, it remains to apply the principles of geomorphy to explain their present forms and their relative ages. These principles were admirably set forth by Professor Dana in his report on the origin of the valleys and ridges of the Pacific islands.[4] They have been applied later to Oahu, more especially by Captain C. E. Dutton.[5]

In the volcanic islands of the Pacific the original form of the land was that of a dome, consisting of basaltic layers of variable hardness, whether solid, vesicular, or agglomeratic, and sloping gently outward in all directions. An abundant rainfall is assured by the contact of the moist air of the trade winds with the elevated mass of land. The resultant streams wear out canyons radiating from the centers or branching from axial lines of elevation. Of the two erosive forces, disintegration and transportation, the latter is the most effective in these volcanic layers, which appear almost like the strata of sediments. In case the rainfall is unequally distributed on the flanks of the elevation, the amount of erosion will vary, as may be seen in the number, shapes, and depths of the valleys excavated.

Because the transporting power of water is greater where the slopes are steep, the valleys become larger in their upper reaches, portions of the dividing ridges disappear and amphitheaters re-

[4] U. S. Exploring Expedition, Geology, pp. 379-392.
[5] Fourth Ann. Report U. S. Geological Survey.

sult; outliers shape themselves out of the original plateau and at the confluence of tributaries; the spaces between the streams narrow to knife edges or may disappear; the walls, originally vertical, change to slopes through the separation of blocks by gravity, which form a talus at the bases of the cliffs. Although frost is absent, so easily are the fragments separated because of the character of the rocks that the excavation is as effective as in colder climates on the more durable ledges. In the lower reaches the streams take winding curves, and thus act laterally against the sides, widening the bases.

The Koolau area is the easiest on Oahu to understand. From the details already presented it is seen to be elliptical, nearly forty miles long, and deeply eroded along its seaward face, with many amphitheaters, outliers, and especially the long cliff opposite Kaneohe Bay. There has been great excavation along the western side of Koolaupoko, but comparatively little on the interior side of Koolauloa. Judging from incomplete observations on the rainfall for the past five years, the average has been one hundred and forty-four inches two miles below the Pali (Luakaha), and about twenty inches near the wharves of Honolulu; but the rainfall is confessedly greater at the crest of the ridge, probably two hundred inches, and it diminishes gradually all the way to the harbor. The fall along the eastern shoreline exceeds thirty inches, increasing to the summit; hence it appears the water should be most abundant along the crest of the range, but greater on the eastern than the western slope, and whatever the fall may be on the Honolulu side it came from the northeast. The erosion has been the greatest on the northeastern side, as seen in the Pali, the outliers, sometimes 2,000 feet high, the ridges running northeasterly, and the amphitheaters. It reached probably to the central axial line of elevation opposite Kaneohe Bay. The cliff can not very well have been eroded by the sea, since there are irregular ridges and chains of hills at intervals of two or three miles stretching out perpendicularly from the wall and ending in promontories. Marine action would have removed these projections. The erosion seems to have been most intense at the road crossing the Pali, since there is a gap worn down to 1,207 feet from about 3,000 feet on either side, and there are two other gaps to the north not far away. Some have explained the presence of the Pali gap and the horseshoe form of the land from Mokapu point to Konahuanui and thence along the main range to the northeast branch, ending at Kualoa point, by assuming a break or fault at the Pali gap or the existence of an enormous crater in the part of the circular ridge just delineated. The best

argument in reply to both these volcanic theories is that the topography is in better agreement with what is known elsewhere to be the result of subaerial erosion. If there were one transverse fault, there must have been three, quite close together, for the first cataclysmic theory; and the theory of the large crater assumes that certain cinder cones and scoria were intimately connected with it, which seems to have been formed in a different way and in later periods.

On the leeward side of Koolaupoko notice has already been taken of about twenty canyons in as many miles. This is where the island is narrow and the rainfall is ample for the work accomplished, though the erosion has been less than on the windward side. Relatively little work has been done farther to the northwest, all the way to Waialua and Waimea. A part of this lack of erosion may be due to a smaller rainfall, stated to have found its maximum at the Pali gap. Certainly erosion has not proceeded for enough to excavate gorges high up, nor amphitheaters. The shallow canyons on the north shore and in Ewa are certainly suggestive of a very scant or recent action. From any hill like Punchbowl or Leilono one can see a fine long stretch of this sloping plateau, which has been utilized for the growth of sugar cane.

The Kaala dome presents phenomena of erosion very similar to those of Koolau, but the greater excavations have been effected on the west side, as evidenced by the valleys of Waianae, Makaha, etc., while the gradual slopes of the Koolau area impinge closely on the latter, and the later drainage has been forced westerly. The work accomplished has been on all sides, whereas the trade winds now blow from the northeast for nine months of the year. The Kaala dome existed before the Koolau mountains were raised very much above sea level. The ocean came perhaps half way across the island, and the trade winds impinged against the basaltic piles, dropping moisture, which excavated the eastern side very completely, together with the Waianae wind gap. Two or more lengthy ridges have been mentioned as protruding easterly from Kaalaa. In later times Koolau came up from the depths and poured over the skeleton ridges on the east side of Kaala, so as to conceal them from view, and underlaid the plateau with nearly horizontal sheets of basalt. This view does not compel us to believe in the existence of climatic conditions different from those now prevailing, and it enables us to interpret what has happened from the varied topography. The greater excavations on the Waianae side have been effected by the Kona storms, both early and late.

This theory is confirmed by observing a more decided contrast on the adjacent double island of Maui. The smaller, older mass of Eeka, in West Maui, has suffered much greater erosion than Kaala, and has also its wind gap, while the gigantic Haleakala, which has poured out sheets of lava almost in historic times, presents only the modern type of canyon erosion on its windward side, and the leeward side has not been affected. The contrast between the two parts of Maui is more marked than upon Oahu, but it is the same in kind and may illustrate the similar sequence of Kaala and Koolau.

THE ARTESIAN WATER SUPPLY.

Among the interesting physical features of Oahu is the abundant water supply derived from artesian wells. All other islands possessing a similar structure are capable of yielding similar returns to effort; so it may be well to present the history of the operations by which great benefits have been derived.

The need of a bountiful supply of water vitally concerns household and agricultural affairs. The numerous sugar plantations need very much water. for irrigating the land. These were at first located upon the other islands like Kauai and Maui whose numerous streams supplied the necessary liquid both for irrigation and transportation. Oahu was neglected because it is comparatively arid. Near Hilo, upon Hawaii, the rainfall amounts to one hundred and seventy-five inches annually; in East Maui to two hundred and thirty inches annually; while about Honolulu it varies from twenty-four to thirty-eight inches; at Ewa and vicinity from sixteen to forty inches, and is quite variable by years, and insufficient for the growth of the cane. At first attempts were made to supply water by irrigation. Like other cities, Honolulu receives much water from mountain streams brought by pipes for household and manufacturing purposes, as well as for the flowage of extensive tracts of rice land. The great need of water led to suggestions of an artesian supply. In 1879 James Campbell sunk the first artesian well upon the island, near the Pearl River lagoon. Water commenced to flow from the depth of two hundred and forty feet, and the auger penetrated thirty-three feet farther. The next one was sunk the following year at the mouth of Manoa Valley, where the discharge proved to be abundant from the depth of two hundred and ninety-eight feet. In the same year Judge McCully obtained a still greater supply from the depth of four hundred and eighteen feet. This last well was within the city limits, where it was easily seen by

the public, who thoroughly appreciated its value. Many other persons followed the example of these pioneers, till now there are more than two hundred wells upon the five leading plantations, yielding daily over three hundred milion of gallons, and there are many more within the city limits of Honolulu.

THE ARTESIAN CONDITIONS.

Oahu presents two series of diversified sheets of rock dipping gently toward the sea from high central points; but the material is volcanic. In the early days successful artesian wells had been sunk through sedimentary strata, whence it was inferred that it would be useless to attempt borings in the so-called unstratified rocks. Many were dissuaded from such attempts by that consideration, yet any geologist would quickly observe the resemblance between these volcanic sheets and a nearly horizontal stratification. There is an alternation of hard basaltic sheets, volcanic clays, ashes, and sometimes limestones which offer the necessary condition for subterranean currents—as they dip gently outwardly on all sides.

The meterological conditions explain the source and spread of the waters. Rain is profusely abundant on the highlands. The trade winds, laden with moisture, drop their burdens on coming in contact with the land surfaces. The maximum rainfall is at the altitude of about 1,200 feet. The preponderance of the discharge, being upon the windward side, determines the place of the most copious streams and the more effective erosion. Hence the domes have been worn away unequally. One side may be entirely removed, and the other be scarcely affected at the surface. If the ridge is narrow at the altitude of greatest precipitation both sides will be extensively worn down. This is well shown on the Koolau upland, where the southeast end has been greatly denuded upon both sides from Mokapu point to the Pali, while to the north, at a greater height, the canyons are less conspicuous on the west side.

The laying bare of the interior of the dome allows the water to sink into the pervious layers, and to flow beneath the surface towards Kaala and the southwest. Only the needful alternation of pervious and impervious strata is necessary to give rise to the subterranean streams which will send water to the surface when pierced by the artesian wells.

The borings upon Oahu prove the alternation of basalt, clay, earth and limestone to the depth of several hundred feet. The principal water-bearing stratum is a very porous basalt, from

three hundred to four hundred feet below the sea level by the shore. It has a hard, impervious cover, sufficiently tight to prevent the passage of water through it. The following general statements concerning the artesian conditions seem to be well established:

1. The presence of a porous water-bearing stratum beneath an impervious cover.

2. Water is reached usually at the depth of from three hundred to five hundred feet.

3. The water flows freely without pumping only in a narrow belt of territory adjacent to the coast line, where the surface is but slightly elevated; which is forty-two feet at Honolulu, thirty-two feet at Ewa and twenty-six feet at Kahuku, at the northeast angle of the island. Wells sunk in higher ground shows the water rising to the level of forty-two feet at Honolulu, above which it will discharge only by the application of a pump.

4. For convenience in obtaining a proper supply several wells are sunk adjacent to each other. Naturally, as development takes place, the number of the wells increases. Thus the Ewa plantation had at first six ten-inch wells some thirty feet apart connected by a single pump, which lifted the water about sixty feet. Later the wells are a foot in diameter in groups of ten for each pump. The water is forced through steel pipes twenty-four and thirty inches in diameter to a maximum elevation of five hundred feet. From various points ditches are dug which carry the water to every field of the plantation. Though the pumps act without cessation, the water never fails; 5,000 acres of land are irrigated from these wells.

5. These wells at Ewa are found to be slightly affected by the brine of the sea. The natural waters of the island contain .0073 per cent. of salt according to Dr. Walter Maxwell;[6] Pacific water holds 2.921 per cent. of the same. One hundred grains to the gallon of water represents 0.14 per cent. The analyst of the Ewa company found that the chlorine present (sodium chloride) was more abundant in the wells nearest the ocean. At station No. 1 the chlorine amounted to 17.61 grains in a gallon. At stations Nos. 2 and 3, farther inland, the chlorine had diminished to 8.18 and 11.97 grains to the gallon. By experiment at several localities it has been found that the salinity increases when the pumping becomes excessive. At Ewa it is stated that vegetation is not at all affected when the number of grains per gallon is less than sixty. At Molokai, where the salinity is greater, it is

[6] 'Lavas and Soils of the Hawaiian Islands,' 1898.

stated that the cane is not affected unless the number of grains per gallon exceeds one hundred.

From all the facts available, the conclusion seems warranted that the underground waters descend to the seas from the highlands and remain free from admixture till the pressure of the ocean exceeds that of the descending stream, when a commingling of the two liquids results. When the ocean pressure becomes greater, because of excessive pumping, the brine will increase in amount. In a smaller island the ocean water will force itself inland quite conspicuously. Molokai illustrates this proposition. Our information is derived from a report of Waldemar Lindgren in the *Water Supply and Irrigation Papers No. 77*. The springs there are of three classes, of which only the first calls for consideration here, (1) those very near the shore, (2) those breaking forth up to the height of 2,000 feet, (3) running streams still higher.

Shallow wells near the shore show the following degrees of salinity or number of grains per gallon, 238, 403, 150, 126, 109, 86, 102, 86; of deeper wells the first gave eighty-six grains at the surface and became ocean water at fifty feet. The second became ocean water at one hundred and twenty-five feet. At Naiwa there are ninety grains of salinity at seventy feet. At Kalamaula several deep wells gave one hundred and two and one hundred and four grains and pure ocean water. The American Sugar Company sank several deep wells at Kaunakakai, of which the first five had one hundred and fifty grains per gallon; others ranged from two hundred and seventy to four hundred and eighty-five grains. The Risdon wells yielded seventy to seventy-nine grains per gallon. Better results appeared in nine wells sunk at Kawela, many of them showing less than fifty grains of salinity. The fresh water is contaminated up to four or five feet above the sea level. None of the underground streams can be more than eight miles in length, and many do not exceed three. It is also probable that no impervious layer protects the underground water as in Oahu.

6. There are springs of fresh water near the sea shore in Oahu which correspond to the artesian fountains. One is the famous Kamehameha Bath near Punahou, a second is near the railroad station at Honolulu, and a third gladdens the thirsty soul at Waialua near the Haleiwa Hotel. Another is at Niu, west of Koko Head. It would seem that the underground water finds its way to the surface through some crevice, after the usual manner of springs, and that it is powerful enough to prevent the commingling of the ocean water with it.

The theory of the subterranean stream from the summits to sea level has been further tested practically by the driving of tunnels to reach the water near its source. Thus derived the water is free from any possible saline contamination, and being delivered by means of a ditch sloping downwards, the expense of sinking artesian wells and the subsequent pumping is saved. In this way a copious daily flow has been obtained from the Waianae side of Kaala, utilized to run a dynamo, besides irrigating several plantations. A second is to be found upon the Oahu plantation. On Maui near Lahaina, a six-million-gallon daily flow is derived from the altitude of 2,600 feet through a tunnel of the same length. There are no springs nor other signs of underground water along the route. It must be permanent, as the flow has been constant for the past two years. Other examples could be cited.

SPRINGS IN THE OCEAN.

After these introductory statements it is possible now to postulate an additional proposition: springs of fresh water arise in the midst of the ocean at some distance from the shore. The facts are not numerous, but are stated upon the best authority. Professor Joseph Le Conte, in his 'Geology,'[7] says that fresh water springs arise in the ocean in the Hawaiian Islands. In reply to my inquiry as to details, he wrote that he had not preserved the memoranda relating to these phenomena, and that they had escaped his memory. No one can doubt the correctness of the statement in view of the existence of the proved underground waters. Powerful streams discharge millions of gallons of water through the artificial openings very near the sea shore. If not intercepted, they must continue a considerable distance out to sea, and hence must well up to the surface amid saline billows.

Further inquiry about these springs in the Territory of Hawaii has resulted in the discovery of several upon Oahu; there is one off Diamond Head, a second off Waialae. At the east end of Maui, in Hana, there was a fortress named Kaimuke, occupied by soldiers in the ancient times. As it was almost an island, communication with the mainland was not feasible in the time of a siege, and for the lack of water it could not have been held except for the presence of submarine springs. The natives would dive down to collect water in their calabashes, which supplied all the wants of the garrison. Other springs were known in the harbor of Hana, and at low tide at Lahaina. Upon Hawaii I

[7] Elements of Geology, p. 74.

found there were fresh-water springs off Kawaiahae, Keauhou and Punaluu.

I was led to pursue the study of these fresh-water springs somewhat further in other than Hawaiian districts, and found abundant illustrations of them in Florida, Louisiana, Cuba and the Persian Gulf, so that we are warranted in looking for fresh water bubbling up through the brine of the ocean in almost any part of the world. It is conceivable that such supplies might be utilized for the benefits of steamships or for household purposes where the local streams are unwholesome or defective.[8]

CORAL REEF.

Oahu is mostly encircled by a fringing coral reef. At low tide one can walk a long distance on this reef in various directions, off the city of Honolulu, near Koko Head, and in Kaneohe Bay. The polyps living on and enlarging the reef are of the genera *Porites, Pocillopora, Astrea, Meandria* and *Fungia,* together with *Millepora,* echinoderms, mollusks, serpulae, gorgoniae, nullipores with sea weeds, etc. The life is much better developed at Kaneohe Bay than at Honolulu, because the trade winds impinge directly against the shore, bringing food in great abundance to the animals, while the harbor is on the lee side of the islands and subsistence is less easily obtained. Where the fresh-water streams of Nuuanu and Kalihi valleys and Pearl river enter the sea, channels are produced, because the animals can not flourish in fresh water. The Nuuanu channel is utilized for shipping, and the Pearl River outlet bids fair to form the entrance to the finest harbor in the Pacific Ocean when the bar at the mouth has been removed.

The great extent of the low apparently drowned land about Pearl River and inland from Waikiki gives the impression of submergence; and on the northeast side of the island Kaneohe and Kahana Bays may be quoted as tending to the same conclusion. This is a controverted point between the advocates of the Darwin and Murray theories of the origin of coral reefs. Doubtless the land is somewhat lower now than it was formerly whichever theory is adopted.

The loose character of the ordinary reef rock is shown in the large blocks used for stone walls and buildings. A better quality is exhibited in the walls of the Kawaéahaa church, and the very best is a compact variety made by the washing of limestone frag-

[8] See Fresh-water Springs in the Ocean. Popular Science Monthly for December, 1905.

ments into fissures and cavities, which have been cemented by its own substance in solution. The sea water has worn the reef into very irregular shapes, not easy to walk on.

The plain of Honolulu rests on coral limestone, beginning easterly near Moiliili church and Paakea, and it has been covered by the basaltic flow of Kaimuki. It crops out in many places within the settled districts, as on the banks of the Nuuanu River near the Palama chapel and seaward from the trolley at Kapalama. A very large excavation in it shows an abundance of corals and shells. Boulders of basalt strew the surface of the unexcavated portion, and it may extend beneath the Kahemaheha Schools and Bishop museum, being fully twenty feet above the sea. The original floor of the crater of Aliapakai consists of coral, and it both overlies and is intercalated in the tuff that came from Makalapa, exposed along the railway in the southeast locks and the islands opposite. Most of the islands and points about Pearl River consist of this material, as at Ford's Island, Pearl City peinsula, Laulaunui, etc. About Ewa plantation the limestone area is nine miles long and two and one-half wide. It skirts the shore and railroad the whole length of the southwest shore of Oahu. At an abandoned quarry three miles north of Barber's Point (Laeloa) lighthouse the best quality of the sandstone is well developed, and was used in the erection of the Saint Andrew's English Cathedral. Alexander Agassiz speaks of this material as a "massive coral pavement sandstone."

There are three varieties of material at this locality: At the base, the underlying rough reef loosely put together, a sandy limestone, and above all, the compact pavement sandstone, capable of affording a good polish. The total thickness is about sixteen feet. This compact rock has been utilized also in the manufacture of quicklime. It is a good place in which to observe the manufacture of the sandstones, for shells and corals are strewn over the beach in all stages from the live animal to worn cobbles, pebbles, sand, and firm rock. Crystals of calcite are frequently seen in the consolidated rock.

Proceeding northerly, Professor Alexander reports a ledge of coral seventy-nine feet above the sea, at Kahe, and seven hundred and thirty feet distant from the water south of Puu o Hulu, he mentions another ledge fifty-six feet above the sea and a quarter of a mile inland; also on the south side of Lualualei, twenty feet high. At the south end of the ridge called Moiliili, the limestone reaches the height of eighty-one feet; at other localities on this coast I have observed limited areas of the same substance more or less elevated.

The plain at Waialua shows many outcrops of the reef; Kahuku, the extreme northern point of Oahu, is the most interesting locality. The Koolau highlands end in a bluff nearly two miles back from the extreme point, rising to a hundred feet or more from a flat plain. This bluff consists of coral rock up to sixty feet, capped by blown calcareous sand now firmly consolidated, which may extend inland to a height of two hundred and fifty feet. At various localities in the neighborhood I found corals and shells in the underlying limestone, but nothing in the sandstone above, save perhaps a shell brought by a hermit-crab. Professor Dana has given a very effective figure on page 302 of his "Characteristics of Volcanoes," illustrating this plane between the two limestones. Nowhere on the windward side of the island do the winds blow more vigorously than here, and hence the explanation of the great altitude attained by this blown consolidated sand. For five miles southeasterly, to even beyond Laie, the coral plain is quite extensive. Knobs of the consolidated sand with inclined strata rise to the height of thirty-five feet, and sometimes suggest an assemblage of kames. Several other localities of coral materials might be mentioned.

PEARL HARBOR SERIES.

The coral reefs and limestones are intimately associated with sedimentary deposits and volcanic flows, partly ashes, often disintegrated. The whole assemblage is really a terrane about 1,000 feet in thickness. It is best developed about the Pearl River locks, and hence for convenience it may be termed the Pearl Harbor series. Probably this series of deposits began in the Pliocene, and the older layers may be a base on which the volcanic ejections commenced to accumulate. Some authors think that extensive Tertiary deposits are necessary for the starting of volcanic activity in every country. If so, parts of the Pearl Harbor beds will be found beneath Koolau and Kaala. This series is evidently to be compared with the thick limestone deposits in the Fiji Islands, supposed by Dr. Alexander Agassiz to underlie the living coral reefs of the archipelago and to have been elevated as much as eight hundred feet.

Owing to thorough disintegration, it is not easy always to discriminate between a decayed lava and a earthy sediment, especially as lavas or ashes are constantly intercalated with strata. I will speak of these deposits at several localities where they may be easily examined. One of the most important may be seen in a railway cutting a short distance east of the Waipio station, west

of Pearl City on the line of the Oahu Railway and Land Company. The deposits seem to be arranged as follows from above downward:

I. Ten feet of a reddish-yellowish earth, constituting the s
H. Six feet of gray slaty colored earth.
G. Two to eight feet of limestone and marl.
F. One to two feet of pure kaolin, best seen in the fields east.
E. Three to four feet of bluish and other clays.
D. Bed of oyster shells, one to two feet thick. Ostrea retusa, Sby.
C. Two and a half feet of ferruginous clay containing large nodular masses of black hard clay, apparently carbonaceous.
B. Six inches of greenish clay, with blue stains of what may be iron phosphate or manganese oxide.
A. Four or five feet thickness of clays, extending downward to the track of the railroad and to an unknown depth.

The uppermost of the layers may be followed along a sort of terrace northerly to the Oahu mill, and the gray layer shows itself wherever a cut has been made deep enough to reach it. West of Oahu mill the kaolin is recognized along the road leading west for one -fourth of a mile, and also along the branch railroad half a mile out from Waipahu station. It comes in contact with basalt, probably unconformably, along the railroad and overlies a pebbly rubble whose constituents are so decayed that they will crumble under the pressure of the hand, and is over an agglomerate that may be connected with the basalt. The Waipio cut is repeated on a larger scale in a railroad cut easterly from the Ewa upper pump (October 14, 1898). The basal greensand is thicker, as is the kaolin and the greater part of the upper material is a red earth, the exposure here being about forty feet thick. It is likely there is a direct connection between the kaolin of the Waipio cut, the neighborhood of Oahu mill, and the railroad cut near the Ewa upper pump. At this locality the lava is in part vesicular, in sheets, very much decayed. Following the railroad to the middle pump, this lava is covered by a thick layer of cobbles and pebbles mixed, which continues almost to the lower pump along the ravine, underlaid by what seems to be very soft lava. This is on the edge of the Ewa plantation plateau, which may be sixty feet above the sea, and said to rise to one hundred and sixty feet where crossed by the Government road.

Crossing over the fish pond from Waipio to John Ii's tomb, the rock is calcareous with fossil shells, either D or G of the section.

East of the Waipio cut along the railroad we see first the upper red earth, and then beneath the same pebbly layer observed in the Ewa ravine. Going west from Waipio, at Hoaeae station is a cut in the red earth, cut by two vertical dikes of sand. About a mile west of Hoaeae there are excavations showing a thick earth covered by the pebbly deposit unconformably, and both by loam. A dike of sand extends downward from the pebbles into the earth.

South from the Waipio cut on the peninsula a calcareous sandstone is found at the south edge of Eo pond. Near Hanaloa pond is a large quantity of marl, and possibly kaolin, G and perhaps F of the section. At the southwest corner of Hanaloa pond is an abundance of limestone with fossil shells and corals. East of this pond the rock appears more like the ordinary reef.

Near Ewa church, northeast from Waipio, the section is more of a volcanic character. At the base is an unaltered basalt of the agglomerate kind, consisting of large stones or spherules, cemented by a reddish material, which is apparently the result of decomposition of the original rock, for there is every grade of transition, from the compact unaltered rock to that containing spherules and that which is entirely a soft earth. There are bunches or areas of the hard basalt in the midst of the softer varieties, and this difference in what seems to be one layer is analagous to variations in the character of the rock at the living volcano. The gases inducing decay are abundant in certain spots and absent from others. The boulders weather concentrically, and are of the same kind with what are often strewed over fields, like the ice-carried stones of glaciated regions. Above this are a few layers of what is very near hematite, a known decomposition product of lava. This is covered by earth, and that by a mixture of sand, earth and rubble. The hill or plateau is capped by red and yellow earths, each a fathom or more in thickness. The total thickness must be sixty or seventy feet.

From the Laeloa craters across the eastern part of the Honolulu sugar plantation or to Halawa station on the railroad the surface is largely composed of the upper earths of the section, constituting the substratum of the soils found to be very suitable for the growth of the sugar cane. At a deep railway cut one-fourth of a mile west from Aiea station is a thick mass of earth, capped by eight or ten feet of coarse pebbles and cobbles, cemented together so as to constitute a conglomerate, all of whose constituents are rounded. These stones increase in size in passing across a stream near the business center of the Honolulu plantation. Starting at the sea level, at Aiea station, the following is an approximate section up to the top of the pleateau, about sixty

feet. At the base, four feet of greenish clay and pebbly earth; one foot of fine volcanic ash, consolidated; four feet of tuff; one foot of clayey ash; pebbles and clay, four feet; tuff and ash, eight feet. Back of this cliff is an indefinite amount of drab and gray earths, with layers of silica. On the summit of the plateau I found marine shells and corals, some of which are like those used for food by the natives, so that this is not a clear case of a submarine deposit, though it probably is, as some of the organisms are not edible. On the branch railroad leading from Halawa up to the sugar plantation is an interesting cut through earth capped by a fine grained volcanic ash, three feet thick, well filled with leaves of dicotyledonous plants. The ash was apparently blown from Makalapa and consolidated. Along the seashore the lower pebbly ash of the Aiea section has been folded and slightly faulted. It is covered by an earth or old soil, which can be traced eastwardly directly beneath the tuff of Makalapa, which comes as far west as Halawa stream.

The Pliocene area of Oahu coincides very nearly with the lowland tracts utilized for the cultivation of sugar cane and sisal, from Barber's Point to Koko Head; perhaps to the altitude of 300 feet entirely around the island. Small patches of the rock appear at Waianae, Waialua, the Kahuku plantation, Laie and other places on the northeast coast. The rock also is extensively distributed below the surface, as developed in the borings for artesian wells. Northeast from Diamond Head Dr. W. H. Dall found fossils in it, referable to the Pliocene, species of *Conus, Purpura, Chama* and *Ostrea,* seemingly extinct. This original announcement of this conclusion was stated as follows:[9] "To sum up, it is concluded that the reef rock of Pearl Harbor and Diamond Head limestones are of late Tertiary age, which may correspond to the Pliocene of West American shores, or even be somewhat earlier, and in the localities studied there was no evidence of any Pleistocene elevated reefs whatever. It is probable that Oahu was land, inhabited by animals, as early as the Eocene."

It would seem that this Pearl Harbor series is a combination of marine deposits, reefs, decayed rock, secondary volcanic products, ashes and solid basalt. The natural conclusion is that volcanic ejections were intercalated with beds of marine origin illustrated further by the finding of a fine black ash intercalated in the limestone of Ford's Island, several miles away from the nearest volcanic vent. At present it is not possible to separate them. Passing southerly toward the mouth of the river, the lime-

[9] Geology of Oahu, Bull. Geol. Soc. Amer., Vol. 11, p 60.

stones grow thicker and merge into the calcareous beds proved to extend into the earth by the artesian bore-holes. Hence there is ground for the belief that the foundation of the whole archipelago is a Tertiary limestone traversed by eruptives.

A recent visit to Wahiawa has added to our knowledge of the facts and to modified conclusions. There have been lavas from both Kaala and Koolau as heretofore explained, meeting in the Kaukonahou gulch, and they are to be distinguished from each other by the slopes of the beds. Connected with the more compact basalt are agglomerate and residual days, still beneath strata of aqueous origin. At the bridge across the stream are fine exposures of the decayed basalt showing excellently the original composition. The cliffs exposed are crowded with the spherules of concentric structure usually soft throughout but occasionally having the solid core present, which remains simply because the work of decay has not been complete. In one place there is an immense concretionary crust of limonite. Passing to the hill south may be seen beds of pebbles, sandy and clayey layers capped by a considerable thickness of residuary clay. There is evidently a considerable aqueous deposit here overlying the decayed basalt. Another fine exposure of the series may be seen as you stand upon the dam and look at the cliff on the northwest side. The discovery of fossil marine shells near the dam at as much as eight hundred feet elevation in the upper sediments will lead to improved conclusions. The basalts from Koolau flowed toward the Kaala sheets, meeting them along the gulch and at the lowest points. Then decay set in, having commenced back in the Tertiary. The later wash from both the mountains has filled all the holes and irregularities and produced the plains sloping downwards to the lowest line, and at the same time extensive sedimentary beds were laid down. It is evident that the ocean covered the plains, making islands of Kaala and Koolau. The gulches leading to Waialua and Pearl Harbor were excavated later after the renewal of the erosion by elevation of the land.

THE LATER VOLCANIC PHENOMENA.

These are manifested as dikes, basaltic craters, tuff cones and ashes. The first traverse both the Kaala and the Koolau basalts; some of them being very olivinitic and are of various ages. The basaltic craters examined are partly in the Laeloa series at the south end of the Waianae mountains, Rocky Hill, Mauumae and Kaimuki to the east of Honolulu. The tuff cones are the most numerous, being at Laeloa, Salt Lake, Tantalus and elsewhere

upon Koolau, Punchbowl, Diamond Head, Kaneohe and the Koko Heads. More or less connected with any of the secondary craters is the Black Ash, which is worthy of special mention.

BLACK ASH.

The city and environs of Honolulu are widely covered by a coarse black ash, cinders or sand of volcanic origin. It is so coarse and uniform that it has been utilized for the removal of all sorts of sewage from the houses to the sea. When the population was sparse this material rendered the laying of cement pipes unnecessary, as it removed the waste matter in a satisfactory manner. Now that the population has greatly increased, there is a call for an improvement over this primitive method of drainage. Nevertheless, facts about the distribution of this ash will still be of importance, as it will be years before all parts of the city can be reached by the new sewers.

The extreme northeastern limit of the black ash is at the base of the Tantalus cone, where it is well exposed along the road for a quarter of a mile. As much as twenty-five feet thickness of it is presented to view here. Some of it is weathered, and there are numerous small nodules scattered through it, varying in size from grains to a length of two inches. Some parts seem to be consolidated lumps, both black and red.

The spur running down to Kakea and Roundtop toward Makiki is covered by this sand, to the obscuration of the underying rock, nearly all the way from Tantalus. A small pond east of Kakea, seemingly an old crater, is sometimes spoken of as the source of the great flood of ash, as it is continuous from it over the top of Kakea, 1,460 feet high, and all the neighboring summits. All these hills have rounded slopes, as if they had been deluged by showers of sand. It poured down the Manoa slope as far as to the trolley line. Roundtop, 1,062 feet, is overlaid by the same material, and everything is covered down to Wilder avenue and beyond. The road from Punahou up to Manoa Valley and the north side of Rocky Hill shows it nearly everywhere. From Oahu College along the base of the hills sloping down from Tantalus and round the base of Punchbowl the amount of this ash reaches its maximum thickness.

Much may be learned by studying the phenomena presented about Punchbowl. First, however, it must be stated that this material is used much for grading and filling holes in the roads, and about buildings. Soon after its application it becomes rusty, and in a year or two the color has completely changed, so that it

is not recognizable. The reddish color of the road and the sidewalks all over the city indicates its presence to those who understand what the black ash may become, and its pulverization gives rise to the dust so freely blown by the trade winds into one's face all over the city. A very prolific source of it is from the slopes of Punchbowl, where it may be seen in abundance, both in the original and altered conditions. At the "Battery," on the summit of the road, this ash occurs in connection with scoria, lapilli, and basalt. It is apparently the throat through which there have been copious discharges. The greater part of the inside of the bowl is covered by it, and those who believe the whole material came from Tantalus would say it had rained down into the bowl from the sky. Nearly opposite the lowest point in the rim of the bowl there is a hill (one hundred and ninety-seven feet) known as the "Powder Magazine," entirely composed of this sand, said by some to have been blown out there from Punchbowl. While this may be true, it is not necessarily so because of excavations of the ravine between the Magazine and the Bowl by running water.

The most westerly exposure of these ashes is at an old cemetery between the Insane Asylum and the Bishop Museum. Obviously the Nuuanu valley may have been filled with this deposit, which has nearly all been removed by fluviatile erosion, leaving this remnant of one or two acres in extent. This may be ten feet thick, as shown by excavations, with caves and pillars of a similar material made to cohere by concretionary attraction. Here may be seen the pebbles overlying the ashes. They have been seen also on the north side of Punchbowl. Hence there are three localities of stones thrown out from Punchbowl subsequently to the discharge of the ashes. It is to be noted that the ashes at the crest of Punchbowl near the flagstaff and those below Tantalus and over Roundtop contain numerous nodules. These are not present in the deposit in the lower grounds about the city. Perhaps their greater weight explains why they are limited to locations near their point of departure.

My conclusion in regard to the origin of this coarse black ash is that it probably originated in at least three craters—Tantalus, the pond east of Kakea, and Punchbowl. The other shore craters, Diamond Head and the Kokos, have poured out freely a similar but finer grained material, and Makalapa may have been the source of the consolidated ash plant beds near Halawa. A better knowledge of the conditions about Diamond Head leads to the belief that the ash on its eastern side came from Kupikipikio. There are beds of this ash cut by the road on the northeast and

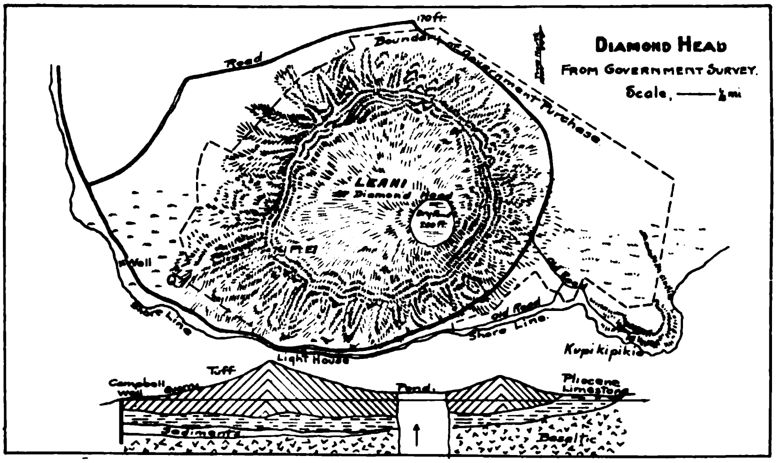
north sides of the Head, sloping toward the east. A part of the material has changed its color from black to reddish, due to weathering. It is generally much finer grained than the ash about Honolulu. It has not been observed about Diamond Head elsewhere than on the Kupikipikio side, where it would have naturally fallen if ejected from the latter opening, being carried by the prevailing winds so as to fall upon the slope of the former. So also had the material come from Diamond Head we should expect to find some remnants of it at least upon the leeward side. The position of Kupikipikio may be better understood by noticing the dark promotory in the distance in Plate 9B taken from high up the Head, and showing the eastern rim of the crater as well.

Chemically this ash ought to correspond to the composition of basalt. The black color may be due to its ferrous content or to grains of magnetite. Scattered through it are white veins and irregular masses in upright stems not unlike the roots of trees. As white particles are also indiscriminately disseminated, their bunching together is probably a concretionary action. Dr. Wilcox of the U. S. Experiment Station, says there is much potassium in this ash, perhaps enough to be of value to growing crops. Some of the white bunches may be potassium silicates, allied to massive zeolites; while most of them are undoubted calcium carbonates probably derived from the underlying coral reefs.

DIAMOND HEAD.

Circumstances have led to an extended study of Diamond Head. There are seven tuff cones near the sea shore on the southwest side of Koolaupoko, of which Diamond Head or Leahi is one. The others are the two at the salt lakes Aliapakai and Aliamanu, Makalapa, a short distance to the northwest, Punchbowl or Puowaina at the base of Tantalus and within the city limits of Honolulu, and the two Koko Heads near the southeast corner of Oahu. They are all composed of palagonite, yellow to brown in color, with resinous luster; they constitute broad shallow saucer-shaped craters with double quaquaversal stratification, the inner dipping towards the center and the other parallel with the outer slope. The brown color is evidence that warm waters were concerned in the making of the cones, not necessarily exceeding the temperature of boiling water.

Diamond Head is the most perfect as well as the best known of all the secondary craters about Honolulu. Visitors recall it as the prominence seen just before reaching port from the east, and again upon resuming their voyage. Artists have vied with one



A. Map and section of Diamond Head.

B. Inside of Diamond Head and Kupipikio.

another in efforts to display this beautiful hill on paper or canvas, and every one is interested in viewing the channeled watercourses upon the outside and the barren rocks as contrasted with the rice fields, coconut groves, and the green plain of Waikiki, a health resort, close to the city at its base. It is a truncated hollow cone, 4,000 feet in the greater diameter of the rim, and 3,300 in the shorter diameter. The elongation is in the direction of the trade wind, and consequently the southwest side is higher and thicker than its opposite. This fact, first stated by W. L. Green and reiterated by all later authors, applies to many others of the secondary craters as well and to the direction of the spread of the eolian beds. The southern highest part is seven hundred and sixty-one feet above the sea at its base, the opposite end being somewhat lower, and there is not much variation in the rim elsewhere. Inside, in the wet season, there is a pond at the lowest point, two hundred feet above the sea, as near as may be to the eastern wall. From the outside Diamond Head looks like a solid hill, and with its reddish tint and apparent strata is very suggestive of buttes in the Chalcedony park of Arizona.

The diameters of the base of this crater are 5,000 and 6,000 feet respectively, making the seashore the extreme southwest limit. The tuff has been recognized in the very deep well sunk by James Campbell near the seashore at Waikiki. Two hundred and seventy feet of tuff were penetrated by the drill beneath fifty feet of beach sand and gravel. Beneath the tuff is a mass of limestone five hundred and eight feet thick; and the section upon Plate 9A shows the relations to each other of the tuff, limestone and basalt as deduced from our various observations. The lowest part of the interior is on one side of the center. A good road follows around the outside of the cone, rising from near the sea level by the artesian well to one hundred and seventy feet where a road turns off to the north. There is very much coral or eolian calcareous sand on the south side of the cone near the lighthouse. Farther east a marine limestone occupies most of the territory.

Sir Archibald Geikie calls attention to the similarity of Diamond Head to Monte Nuovo near Naples. This is a scoriaceous tuff cone which was thrown up in a few hours in 1538, while there was other activity for a week. Most travelers visit it, so that it is an object well known. It is four hundred and eighty nine feet high and about one and a half miles in circumference. The larger part of the famous Lucerne lake here was filled with the stones, scoria and ashes that were ejected at the time of its origin. Among the fragments thrown out were pieces of Roman pottery and marine shells, which happened to be situated in the

path of the ascending outburst. I have been in the habit of using the known history of Monte Nuovo in my lectures for the past forty years to illustrate the formation of tuff cones, emphasizing the brevity of the process, the stratification of the material (double quaquaversal), and the lack of any disturbances in the adjacent territory. The temple of Pluto was partly covered by the debris, but its level has not been affected, as it would have been if the cone had been formed in the manner suggested by L. von Buch and Elie de Beaumont. They believed that the conical shape proceeded from an upheaval or swelling of the ground around the vent from which the materials issued.

Dr. S. E. Bishop has very forcibly stated the brevity of tuff cone eruptions in the *American Geologist*,[10] using Diamond Head for the illustration of the subject. Such a cone, he says, "could have been created only by an extremely rapid projection aloft of its material, completed in a few hours at the most, and ceasing suddenly and finally."

The first proof of this proposition is the extreme regularity of the elevated circular rim of the cone. Two-thirds of the elevated perimeter represents nearly a complete circle about 5,000 feet in diameter, and most of it is about four hundred and fifty feet above sea level. The tuff has uniform quaquaversal layers dipping outwardly about thirty-five degrees, but less upon the inside, pointing toward the center. The southwest angle reaches the height of seven hundred and sixty-two feet, because the strong trade wind deflected the lofty jet of tuff to leeward and piled it up disproportionately.

The second evidence of the brevity of the eruption is derived from an arithmetical computation of the time required to deposit the actual mass of the cone by a fountain of adequate height to deliver its ejecta upon the existing rim of the bowl. The total mass is thirteen billion cubic feet of tuff. This could have been discharged by a fountain with eight hundred and seventy-five feet of velocity per second, raised to a height of 11,925 feet in two hours' time. This is given as an approximate estimate only, and he is disposed to increase the velocity and reduce the time, with a section area of 5,000 feet.

These statements of the symmetry of the cone and of the time required for the deposition of the mass are thought to forbid any other conception of formation.

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[10] Vol. XXVII, 1901, p. 1.

PUNCHBOWL AND DIAMOND HEAD COMPARED.

The structure of Punchbowl is like that of Diamond Head. It is mostly composed of tuff, much of which on the side toward the city has its seams filled with calcite. In the quarry below the reservoir both calcite and zeolites are found, and an occasional piece of basalt. The phenomena prove that the black ash overlies the tuff, and that a long interval must have elapsed between the ejection of the two materials, because the inferior one has been weathered. It is probable that the first material came from beneath the sea, while the later ash, though issuing from the same vent, did not come in contact with water, and with it came another basalt, that on the summit of Punchbowl and in the dikes radiating from it. The extent of the tuff to the southwest is shown in the well boring at the Queen's Hospital, where forty-seven feet of it is reported underlying thirteen feet of lime sand and ten of black ash. The Tertiary is well shown in a cutting near by on Vineyard street, fifteen feet of sand with shells being exposed beneath the black ash.

Similar relations of the tuff, soil, and ash have been observed near Moanalua, where the tuff has been covered by an ash in which may be seen upright trunks of trees.[11] Rather than assume the ashes to have been erupted simultaneously in the Honolulu district, it may be better to say that similar eolian materials have been discharged at intervals through an unknown part of Tertiary time.

Doctor Dall has noted the greater abundance of limestone in Diamond Head, where the tuff is fairly saturated with it, than in Punchbowl. A walk up the southwest slope of Punchbowl will satisfy any one that the seams are as fully filled with this mineral as in the northern part of Diamond Head, and in the quarry it is not wanting, accompanied with zeolites. It was stated above that over five hundred feet of limestone underlies the south end of Diamond Head, and only thirty feet in the well at the Queen's Hospital adjacent to Punchbowl. As the volcanic ejection brought up the underlying rock, Diamond Head should show very much more of it than Punchbowl. It is also on the seashore adjacent to the reef from which come quantities of eolian calcareous sand. Punchbowl is half a mile distant from the seashore, and therefore would not be expected to be supplied so abundantly with blown sand.

An examination of the inwardly dipping layers near the high-

[11] Geology of Oahu, Pl. 6, Fig. 2.

est point of Diamond Head reveals a very liberal supply of limestone. It was here that I found coral and shells in 1883. The photograph in Plate 9B shows the abundant supply in the layers of tuff in the foreground on the right-hand side. The standpoint is quite near the summit, and the view was taken to show the rim of the cone, the interior, and the black promontory of Kupikipikio in the distance.

In this connection it is proper to advert to the abundance of limestone in the inside of the crater at Salt Lake. Not merely are the fragments abundant, but the original reef itself must be present.[12] The western Koko Head is equally prolific with limestone blocks, though from a hasty examination I am not prepared to say that the original ledge can be detected. The limestone has not been seen in the lowest part of the inside of Diamond Head.

THE TALUS-BRECCIA DEPOSIT WITH LAND SHELLS.

At the southern base of Diamond Head, at a quarry not far from the terminus of the electric road (1905), is an extensive excavation in a talus-breccia of tuff with a calcareous cement. This carries shells of *Lapachtinia, Helicona, Pitys, Succinea, Pupa* and *Helix lamblata,* as heretofore reported. A similar deposit may be found skirting the base of the cone, probably on every side as well as in the inside, but it is seen to the best advantage where the new road has cut into it between the quarry and the lighthouse. Near the lighthouse the specimens of shells are particularly abundant because of the greater magnitude of the excavations. To the list given above may be added *Amastra* and *Endodonta,* and Professor G. H. Perkins found in addition, lower down the cliff, the remains of crustacea. Mr. C. Montague Cooke, of the Bishop Museum, has discovered additional localities of these shells upon Rocky hill and in Manoa valley, scattered among the uncemented talus blocks of that region, and in the surface soil. The geological age of all these localities must be the same. The list of them, including a few collected by Mr. Cooke and identified by him, is as follows: *Lepachtinia,* five or six species; several of *Amastra; Tornatella,* two species; *Pupa; Endodonta,* two species; *Helicina,* one species; *Succinea.*

Mr. Cooke speaks of them as "subfossil." It remains to be determined whether any of the species are extinct.

This talus-breccia must be newer than the date of the eruption

[12] Geology of Oahu, p 38.

of the tuff, because it is the same material, detached from the cliff by gravity after consolidation. The cementing substance may be either fragments of lime in the tuff or blown sand from the seashore; and there must have been quite an interval between the ejection of the tuff and the presence of the animals, because the base rock must have suffered disintegration so as to allow the growth of herbs and small trees and the migration hitherward of the Mollusca. This interval was probably the same as the one indicated at the Punchbowl and at Moanalua.

It is highly probable that these shells represent a late stage of the Pliocene, partly because they seem to be older than the existing handsome species of Achatinellidae and partly because of the presence of a marine deposit overlying the quarry mentioned above. Two views of the origin of the Achatinella have been promulgated—the first, that of Professor Pillsbry, that it has come from a type analogous to *Limnaea,* as determined by anatomical characters; the second a derivation from *Bulimulus,* because of conchological peculiarities.

THE LATEST SUBMERGENCE AND REELEVATION.

It would seem as if there must be evidence of the submergence of Oahu after the accumulation of the talus-breccia to the depth of two hundred and fifty feet. The relation of the deposit to the talus-breccia may be seen at the quarry, where at the altitude of about forty feet there is a red earth with many marine remains directly overlying the talus-breccia. Beside the mollusca, there are corals and remains of fish. This is the only place where the relation of these shells to the talus-breccia is clear. What seems to be the same material rises to two hundred feet at the north base of Diamond Head and is also seen at the lower levels. I do not recognize anything like a shoreline, but the marine shells are frequent. Near Doctor Wood's summer house, one hundred feet above the ocean, at Kupikipikio, are *Cypreas* and *Turbo,* both shells and opercula. The surface is strewn with rough blocks. The shells are seen when the lava fragments are thrown to one side in a very red earth, the residuary remains of the Kaimuki lava.

A study of the fields at the Waialua plantation gives related results. The cultivated tracts seem like aqueous and residuary deposits, utilized to the height of about three hundred feet. I found shells and opercula of the marine gastropods in numerous localities and *Melanias* up to two hundred and fifty feet altitude.

I had no opportunity to see these remains in any excavations; they all lie on the surface of the ground.

I think a little search will prove the existence of seacliffs toward Kaena point, to the west of Waialua. Looking from the railroad train, there seem to be three wave-cut terraces in the basalt, the highest one at about the level of the shells picked up from the sugar fields. The excavations may not be strongly marked, as it is presumed that the time of the submergence was brief; but it seems evident that there must have been a very recent depression of the island to the depth of two hundred and fifty feet, very likely in the Pliocene. If so, the age of the smaller land shells in the talus-breccia will be established. As has been remarked, it would seem necessary for as long a period as that to have elapsed to account for the development of the Achatinellidae.

RELATION OF THE BASALTIC EJECTIONS TO DIAMOND HEAD.

The question has arisen, What is the relation of Kaimuki to Diamond Head? In my geology of Oahu I have referred to the meeting place of the two rocks, at the highest point reached by the road in the col between the two cones and near the new Fort. The tuff has been rained down upon the basalt, and therefore Kaimuki must be the older of the two ejections. The presumption is that the other similarly situated basaltic craters, like Mauumae and some of the Laeloa series, were of the same age.

Some of the basalts must have been erupted later than the tuff, after the land had risen, because the material is neither fragmental nor hydrous. They are later than the limestones which they have cut through.

Some of the artesian wells show the presence of a thin basalt intercalated in limestone or earth, thus indicating an earlier eruption.

ORDER OF EVENTS IN THE GEOLOGICAL HISTORY OF OAHU.

From the descriptions now presented it is possible to make out the order of the principal events in the geological history of this volcanic island. We are satisfied with the existence of Tertiary deposits antedating the rise of the earliest basaltic land, but will not consider whether there may have been any rising of the ocean floor in connection with the eruptions.

1. At the base of Kaala igneous eruptions commenced under water to accumulate sheets of basalt until finally the island of

Kaala, a smooth dome rose above the waters, which slowly became covered by vegetation derived from distant regions.

2. This dome became extensively channeled by streams produced as now by the condensation of the moisture brought by the northeast trade winds and Kona storms. Both sides suffered erosion.

3. The island of Koolau came up quite near to Kaala in a similar manner, and lava flowed down so as to conceal several hundred feet altitude of the northeast flank of Kaala. Koolau extended out to sea several miles farther to the northeast than at present.

4. Coralline and molluscan limestones commenced to grow as soon as the reef-building animals could migrate hither. Doubtless the work commenced in the first period, and has continued ever since, coeval with the other phases of growth. If we were to judge of age from the amount of work accomplished we should say the earlier stages of growth correspond to the work done elsewhere in the later Tertiary. The slow upbuilding of the volcanic domes and their subsequent erosion required an immensely long period for their accomplishment. The island was also a thousand feet higher than at present, if the Darwinian theory of the origin of coral reefs is true.

5. Eruption of the amygdaloidal basalt at the Pali.

6. The olivinitic basalt formed laccolites at the Pali. Some of the dikes, both in the Kaala and Koolau areas, may have filled fissures at this time.

7. Eruption of an igneous agglomerate containing pebbles of olivine; may have produced craters in both areas; developed typically at the Pali.

8. Quite widely extended ejection of red ash, clinker, and lava at the Pali, and the formation of Makakilo and Kupuai of the Laeloa craters; some of the Tantalus series of craters.

9. Ejection of some of the basalts penetrated in sinking artesian wells; including also most of the Laeloa craters, Kuua, Palailai, Kapuai; also Kaimuki, Mauumae, Rocky Hill.

10. Tuff craters, probably not all active at the same time—the Salt Lake group, Punchbowl, Diamond Head, the Koko Heads, Kaneohe group, etc. The tuffs came up through coral reefs, the land probably being lower than at present; vegetation as flourishing as at present. Five substages indicated along Oahu Railway and Land Company near Moanalua station.

11. Decay of the surface of the tuff and, of course, of all the other rocks, so as to produce soils.

12. Discharge of ashes from Tantalus, Punchbowl, Diamond Head, Koko Head, and elsewhere, followed by showers of stones.

13. Dikes cutting Punchbowl, Diamond Head and coral reef, Kaena point, Kupikipikio, and Koko Head.

14. Time of the accumulation of calcareous talus-breccia with Achatinellidae at Diamond Head.

15. Depression to the extent of two hundred and fifty feet.

16. Elevation to the present level. Accumulation of dunes.

MOLOKAI.

Molokai is a long narrow island running east and west, thirty-five miles in length, seven in average width and with an area of two hundred and sixty-one square miles. The eastern end is the highest, Kamakou Peak attaining the altitude of 4,958 feet. Nearly half of the eastern portion presents precipitous walls toward the sea, seemingly inaccessible as seen from a steamer. From the middle portion a low peninsula, Kalaupapa, extends to the north about three miles, upon which is situated the famous Leper Sanitarium at Kalawao. As this peninsula can be reached only by vessels the situation is an admirable one for the segregation of these unfortunates. Canyons have been worn back into the cliffs from one to six miles in length. The second highest peak, Olokui, 4,600 feet, is situated upon a small table, connected with Kamakou by a crooked knife-edge ridge, almost separated from it, but channeled on all sides in the amphitheater style of erosion. The land slopes on the west side to some two or three hundred feet of elevation, and then rises to Mauna Loa, at a dome 1,382 feet. Thus the island is a doublet, like Oahu. On the south side the slope is gradual, and the surface has been cut into numerous gorges, more than fifty in number upon the eastern section and nearly forty upon the southern and western slopes of the western section.

The plain of Kalaupapa has been traversed by lava streams of a recent date, issuing from small craters. Among them is a famous opening or well called Kauhaku. It is simply a hole in the ground with no exterior crater. Its depth is not known, but it cannot be a great distance to the sea level. Currents of air commonly circulate through similar holes elsewhere, at all altitudes.

Molokai does not furnish a stable supply of water adequate to the support of extensive sugar plantations. It is because the pumps exhaust the fresh water and then the brine of the ocean takes its place.

Relief Map of Maui

Lanai is situated south of Molokai and west of Maui, so that it must be protected from the winds. It is twenty miles long, eight wide. The southeastern end is the highest, the most elevated point being 3,400 feet above the sea, and it slopes gradually to the northwest. Craters can be made out, and there are many valleys radiating from the highest point, but streams of water are wanting. The soil is red, and the vegetation appears stunted.

Kahoolawe is not unlike Lanai, but of smaller dimensions, having an area of sixty-nine square miles, with its longest axis N.E.—S.W. It is on the lee side of East Maui, separated by a channel about a mile in width. The apex of the island rises to 1,472 feet. The surface is comparatively smooth, not broken by ravines. There are no streams but small pools of fresh water. There may be a crater at the highest point, and the layers seem to dip outwardly from the center. Both Lanai and Kahoolawe have high cliffs on the lee shore and gentle slopes to the windward. The ancient volcanoes of both these islands must have been entirely disconnected with each other or with Maui.

MAUI.

The general topographical features of Maui are shown in the illustration Plate 10. It should be said that the reliefs of Kauai, Oahu, and Maui are copied from models of those islands that were prepared and copyrighted by Professor Willis T. Pope of the College of Hawaii. They are a great improvement upon the reliefs of an earlier date, for which I was responsible, with the help of Professor Edgar Wood of the Normal School. I have ventured upon some slight improvements, such as to change the scale in the title, the removal of much lettering that is too small to be readily seen, and to the use of larger letters more easily seen but fewer in number. The descriptive matter upon each of the reliefs is the same with that given by Professor Pope, except that I have used the figures for the Sugar Crop of 1907 rather than of 1906.

This is a double island just like Oahu, with a similar history, the western part being much the oldest. The areas are also more completely separated, the width of the neck being about six miles, and the altitude at the middle one hundred and fifty-six feet instead of eight hundred and eighty-eight on Oahu. The material of this low ground is an eolian calcareous sand. West Maui rises to the altitude of 5,788 feet in Puu Kukui, two miles south of the crateriform Eeke, 4,500 feet. The amount of erosion produced by the streams is wonderful, as many as eighty canyons

being delineated upon the map. Of these five are notable for their great size, the first pair, so to speak, consisting of Iao running upwards westerly from Wailuku and joining Olowaina upon the southwest, with a knife-edge gap between, of the altitude of nearly 3,000 feet. This is comparable with the Nuuanu valley and the Pali of Oahu. The longest ravine is from Kukui due north to the sea, about eight miles in length. On the northeast side, and north of Iao are the two valleys of Waihee and Waiehu, at whose base is a large sugar plantation. South of the Iao-Olowaina line are as many as twenty deeply incised canyons, somewhat irregular. There are two pinnacles, one in the Iao valley three hundred feet or more high, somewhat suggestive of the Tower of Pelée in Martinique, and the other Puu Koai on the north side next to the sea, six hundred and thirty-four feet high.

East Maui has more liberal dimensions, culminating in the Pendulum Peak or Pukaoaa 10,032 feet, on the edge of the great caldera Haleakala, and with an area six times greater than that of West Maui. Because of the great altitude the trade wind deposits its moisture chiefly upon the east side, thus providing perennial deluges below the contour of 7,000 feet on the east, and leaving an arid desert upon the lee slope. The caldera may be compared to an elbow bent to an acute angle, the outer border corresponding to the "crazy-bone" being sharper than the inner, say 45° and 80° respectively. It is five miles from angle to angle, four miles from the south wall to the proper north edge of the platform of 7,000 altitude; nearly seven miles from Pendulum Peak to the east wall. These walls slope both northerly and easterly from 2,500 and 3,000 to 2,000 feet at the north and over 1,000 feet at the south. The more northern is the Koolau gap, the southeastern the Kaupo. The floor is essentially 7,000 feet high, with sixteen craters made of cinders in the southern part of the depression, of which the highest is nine hundred feet, and none of them less than four hundred. It will be noted that this depression corresponds to the wind gaps seen in the median part of all the Hawaiian highlands like the Pali on Koolauloa in Oahu and the crest of West Maui. Yet the origin of the Haleakala gap is most probably to be sought in igneous rather than aqueous action. I do not find that observers have described the character of the Koolau canyon, whether distinct flows of lava can be seen, or whether it is a valley of erosion to a considerable extent. The Kaupo valley is filled with igneous discharges sent forth before the development of the sixteen small craters, which by the map seem connected with Kaupo rather than with Koolau. The complex structure of the caldera will be set

PLATE 11.

A. Bird's-eve View of Haleakala on Maui.

B. Inside of Haleakala.

forth later. By the Pendulum investigations of Mr. E. D. Preston, it would appear that Haleakala is a solid mountain, in distinction from Mauna Kea and Mauna Loa, where subterranean lava tunnels abound.

Two views of Haleakala are presented. Plate 11A is a restoration—an attempt to show the appearance of the caldera as if one were situated in a balloon a thousand feet above the highest point. It is reduced from a painting by E. Bailey, based upon W. D. Alexander's early map. Plate 11B is a photograph of the south wall of Kaupo, with views of some of the smaller craters inside the pit, taken by Mr. R. C. Barrows of the University of Wisconsin.

The most striking feature in the topography is the presence of numerous canyons wherever the rainfall has been considerable. East of Kaupo there are twenty-two of them before reaching the east point of the island; thirteen between Nahiku and the outlet of Koolau, twenty-six between Koolau and the western limit near Haiku. Although there is plenty of rainfall in the district of Hana, the canyons are wanting: due, one would say, to the recency of the lava flows there. The map seems to indicate an eastern projection of the island. There is an enormous depression called Kipahulu to the eastward of Haleakala not yet geologically studied, which with some other smaller craters would seem to have been competent to discharge the lavas of Hana. The absence of deep canyons on the west side of Haleakala has been already stated to be due to the absence of any considerable rainfall. There are, however, a dozen shallow ones there. Thus East Maui furnishes excellent illustrations of the formation of canyons as well as their absence, upon the same high mountains.

Between Kaupo and Hana upon the south side of the island it is impracticable to build roads along the sea shore, and consequently the traveling is excessively wearisome, it being necessary to descend into every gorge and rise to every ridge from four hundred to seven hundred feet each. The intervals between them are rarely as great as half a mile, and often the separating platform is a mere edge. The trail is well built, but the constant succession of ascents and descents renders traveling there very tiresome for the beasts of burden. The ravines are represented to be wonderful scenes of tropical vegetable splendor.

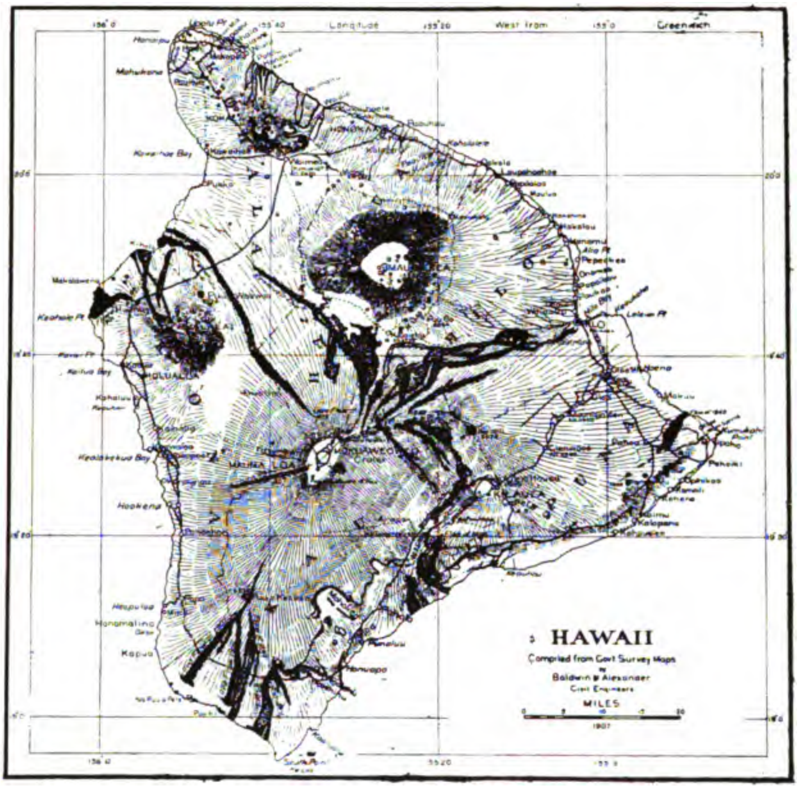
The abundant rainfall upon Maui has been utilized for irrigating the sugar plantations upon the west and north sides of Haleakala. There was first the one built in 1878 by Baldwin and Alexander. Next came one situated on the same windward side of the island, constructed in 1879-80 by Mr. Spreckels. It is

about thirty miles long, of fifty million gallons daily capacity delivered at an elevation of two hundred and fifty feet, and is known as the Haiku ditch. A third, called the Lowrie ditch, was finished in 1904. It gathers the water at an elevation of 1,250 feet and discharges into the other ditches. It is ten miles long, of which seven and one-half are in tunnels, the rest being in open canals and flumes. The tunnels are all in solid rock, thirty-eight in number, eight feet wide and seven high, with a daily capacity of eighty-five million gallons. Water is conveyed by these tunnels as far as to Kihei on the south shore of the island. Upon West Maui the Honokahau ditch has been completed recently, having a daily capacity of thirty million gallons. It is thirteen and a half miles long on a grade of five feet per mile, has two hundred feet of thirty-six-inch syphon pipes and three and a half miles of tunneling. The water is delivered at the elevation of seven hundred feet. Six million gallons are obtained at an altitude of 2,600 feet from a tunnel in solid rock 2,600 feet long, whose exterior surface showed no signs of water like springs and streams. This ground water is very constant, fluctuating slightly with the rainfall in the immediate vicinity, while the mountain behind rises 3,000 feet higher than the excavation.

HAWAII.

Hawaii is the most important island of the archipelago, in all respects, whether physiographic, volcanic or historic. It is the largest, with an area of 4,015 square miles, has its culminating point in Mauna Kea, 13,825 feet, and has been made by the coalescence of the volcanic discharges from five volcanoes, Kohala, Mauna Kea, Mauna Loa, Hualalai and Kilauea. An inspection of the map, Plate 14, will at once illustrate the special development of these several areas. First is Kohala at the north end, with its enormous cliffs and deeply dissected canyons, indicating a greater antiquity. It stands apart from the other centers with a smaller area, separated from both Mauna Kea and Hualalai by comparatively low ground. Second, Mauna Kea is covered by cinder cones and is more like the volcanic piles of other countries than its typical Hawaiian neighbors. Its seaward border is precipitous but with much less elevation than its neighbor on the north, while on the south Kilauea lacks any considerable cliffs opposite the sea. From Mauna Loa it is separated by a col 6,600 feet high. The former greater extent seaward is obvious. Third, Mauna Loa barely reaches the sea, or not enough for the development of cliffs. The protrusion seaward is clearly ap-

PLATE 14.



Map of Hawaii.

parent upon inspecting the map. It lies between the two volcanoes Kilauea and Hualalai, both of which come to the sea level without cliffs, because there has not been time enough to develop them.

Hawaii affords the data for observing the differences between subaerial and marine erosion, as well as their combined action. The northeastern shore has felt the influence of the waves of the Pacific, urged along for thousands of miles by the trade wind. Probably the action of these sea-waves is nowhere exceeded in their efficiency, and there is a direct connection between the amount of the erosion or the size of the cliffs and the length of time during which the action of the water has been operative.

In Puna there are no cliffs of enough consequence to be delineated upon the Government map, and the lava has flowed to the sea within a hundred years. The same is true about the village of Hilo: so that here the erosion has been of the least consequence. The slope seaward is about one hundred and twenty-five feet to the mile. Towards Kohala it is somewhat steeper and has been cut into ravines, nearly seventy in number, for forty miles, while the shores are vertical cliffs. Hence the road must cross all these ravines in zigzag courses, rendering traveling in Hamakua very exhausting. There are many sugar plantations along this coast, often times the streams fall over precipices not far below the road, so that it is dangerous to wade across the water where the current is strong. If one loses his footing he will be carried down over precipices sixty to seventy feet deep. Captain Dutton estimates that the sea has encroached upon the east base of Mauna Kea as much as two or three miles. The cliffs and the country behind can be seen very perfectly as one sails along the coast. The gulch named Hakalau, opposite Mauna Kea, is said to be nearly 2,000 feet deep. The road passes along the seashore at the mouth of the valley.

After passing the coast of Hamakua, the cliffs increase in height within the Kohala district. They are 1,500 feet high for a distance of twelve miles, and the land recedes very perceptibly where the erosion has been the greatest. Streams of water can be seen from the passing steamer, pouring down these high cliffs. The canyons are very wide and the plains at their bottoms, a mile wide, are very fertile and constitute the favorite places for residences of the native Hawaiians. Three of these canyons are very well shown upon the map. Waipio is the most celebrated. Communication between these valleys is had only by means of canoes. The people living there are as much isolated as upon Molokai. So immense are these valleys that some have

been led to ascribe their origin to volcanic disturbances. It is better to adopt the theory of erosion, and to believe that the land formerly extended some ten or twelve miles out to sea, and consequently the original Kohala island must have had an antiquity as great as either West Oahu or West Maui. The curvature of the Waipio valley instead of representing a block of lava fallen down from the main mass is an illustration of the tendency to form amphitheaters by erosion. Doubtless there have been examples of the falling of segments by faulting, in order to account for the depth of the cliffs under water. This is the style of change common upon Hawaii, as seen in the long cliffs in the Kau desert south of Kilauea.

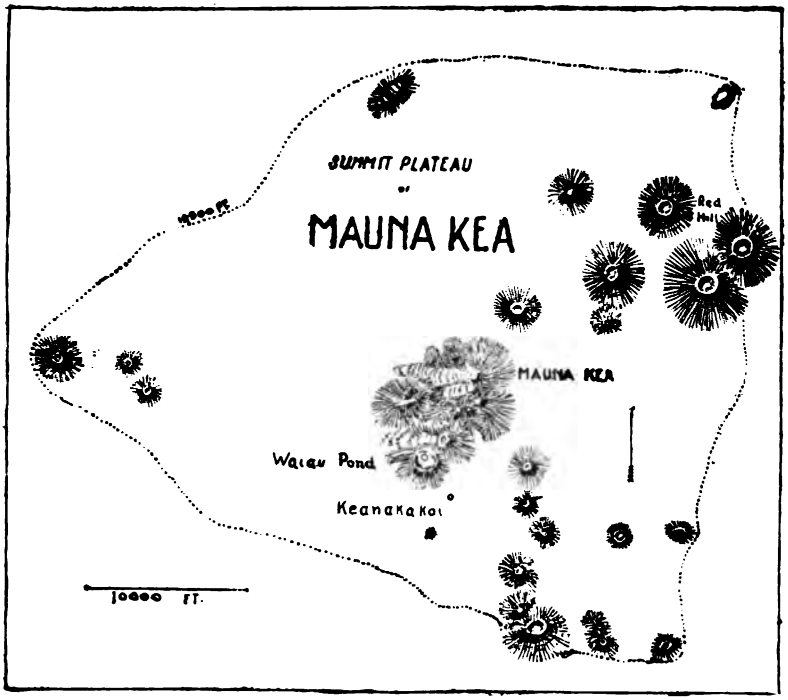
The greater age of Kohala is also indicated by the vegetation; the forests there are more diversified than any others upon the whole island.

The earlier authors have usually agreed that the region of Kohala was the oldest part of Hawaii. It is easy to go further and modify the usual statement of the growth of the archipelago from N.W. to S.E. by saying that in an ancient period Kauai, West Oahu, West Maui and Kohala constituted the group, all of about the same age. It is conceivable that several of the existing islands—like Maui, Molokai and Lanai—may be consolidated in the next geological period, and constitute an area comparable with that of Hawaii.

MAUNA KEA.

Mauna Kea is the *white* mountain of Hawaii as indicated by the name. It is capped with snow for a longer time and more often than any other summit in the archipelago, because of its greater altitude, 13,825 feet. The snow prevails from November till March, and intermittently later in the year. I never saw snow of a more dazzling white than what fell in connection with thunder showers on July 23, 24, 25, 1905. The snow furnishes the material for the pond Waiau, one hundred and twenty-five feet long above 14,000 feet. This body of water is situated in the midst of an extinct crater. Ice forms in it even in the summer, the temperature falling as low as 13° F. in the middle of July.

Mauna Kea is a cone with a diameter of thirty miles, rather ellipsoidal, with a northwesterly trend, and a corrugated surface, whether seen from the north or south. See Plate 13. Mauna Loa differs from it by having a comparatively smooth surface. Being younger there has not been the opportunity to multiply cinder cones upon it. If the early history of Mauna Kea has been



A. Summit Plateau of Mauna Kea.

B. Cinder cone near summit of Mauna Kea.

PLATE 13.

Mauna Kea from Hilo.

like that of Mauna Loa these cinder cones cover an ancient caldera. There are many canyons about the base of Mauna Kea which are likewise criteria of a greater age.

Mauna Kea is ascended from the east and southwest sides, or from the coast and the sheep ranch Humuula in the col between Kea and Loa. The slope is usually as much as twelve degrees, but more upon the north side. Mauna Loa may show a slope of seven degrees where steepest, but only four degrees where the whole dome is kept in view.

There is a sort of plateau upon the higher part of Mauna Kea above the contour of 12,500 feet, with an area of from thirty-five to forty square miles. It is shown in Plate 12A, which is a copy of the map prepared by Prof. W. D. Alexander in 1892 when in the company of the party of Mr. E. D. Preston of the U. S. Coast and Geodetic Survey. Upon this plateau above the contour of 6,500 feet are scattered more than seventy-five cinder cones, mostly of a red color. Similar cones are scattered less numerously upon the flanks of the mountain. Towards the southwestern base some of the material is black, though red at the surface because of weathering. Some of it cannot be distinguished from the black ash covering a large part of the city of Honolulu.

These cones correspond so closely with the related "terminal" craters at the heads of the flows upon Mauna Loa that I reproduce a sketch of a very fine one seen from the summit of Mauna Kea, Plate 12B, taken from Mr. Preston's report, U. S. G. & G. S., 1893, The observer stands upon the very summit of Mauna Kea, Kukahaula, and looks southwesterly. In the foreground appear the rough blocks at the summit, one crater near by and two or three others in the distance, besides the one that is so prominent in front, and is taken as the representative of the others. It has the typical slope of the true cinder cone. Judging from the phenomena presented at the making of the corresponding cones upon Mauna Loa there was a stream of liquid lava either quietly welling up or rising as a column in the center. As this material fell to the ground about the orifice, it was divided into fragments known as cinders or lapili, and then still finer volcanic ash and dust, of which the impalpable part may be blown into the atmosphere and transported by the wind to great distances. The Mauna Kea summit cones are usually perfect; those that appear elsewhere have one side worn down to permit the still liquid streams to flow away. Later this crevasse was enlarged by the action of subaerial water seeking a lower level.

The cone at the summit is covered by blocks of consolidated lava, including many bombs, some of them three or four feet

long in shape like ornamental ear-pendants. Those that I examined had a nucleus of olivine enveloped by a white basaltic rock—much as if the darker silicates had been segregated into a central mass while the whiter feldspars aggregated themselves to the exterior. Observers who are not experts may be excused for calling this material granite; so much does it superficially resemble that rock. The whole mass, before the green core and white exterior have been broken apart is properly a volcanic bomb.

This grayish white rock seems to be identical with a stone used by the Hawaiians very extensively as a sinker in catching cuttlefish. I once saw a pile of them, perhaps two hundred in number, gathered from many different localities. Doubtless many of them came from this mountain because at Keanakakoi close by Waiau is the quarry from which the best of the Hawaiian adzes and poi pounders were obtained. The implements made of the white stone are elliptical, flat upon the bottom and encircled by a groove along the major diameter. To this stone elegantly colored shells like the Mauritanian cowrie (*Cypraea*) are fastened by a string from which large hooks are suspended. This apparatus is sunk in shallow water where this cuttlefish has its home. The creatures are attracted by the bright colors, approach the bait and have their tentacles so entangled in the hooks that they are easily drawn to the surface and captured. The flesh of this animal constitutes a food of which others besides natives are fond.

The stone of which the adzes are made is very fine grained and compact and of a light gray color, with a darker fracture when fresh, and it flakes readily. I do not find any notice of its petrographical character, but can understand it to be a basalt with much triclinic feldspar present. There are plenty of rejects and fragments that have been chipped off from the manufactured tools about the quarry.

The plateau is so high that men and animals are much affected by mountain sickness when traversing it. Except for the exhaustion of the horses when they reach this level there is no difficulty in riding all the way from the base to the summit. The sides of the cinder cones are steep, but the route may be made circuitous, avoiding sharp grades.

Upon a clear day the view from this summit is impressive. Besides the lowland adjacent and the contiguous summits of Mauna Loa and Hualalai, Haleakala stands out conspicuously. Mauna Loa is marked by a serrated gap, and parts of the encircling walls are distinct, the summit being about twenty miles distant.

But the most instructive view is that of the several historic lava flows, of 1843, 1852, 1855, 1880, and 1899. They are all narrow and tortuous near their sources, spreading out low down into black extensive areas almost coalescing. Besides these others of prehistoric age can be traced—and nowhere can one be more impressed by the fact that the mountain has been built up by intermittent lava flows, and can appreciate the certainty that millions of years were required to construct this eminence.

Several of the party of the Blonde ascended Mauna Kea in July, 1825, accompanied by a "missionary and botanist." Rev. Mr. Goodrich of Hilo writes of an ascent made by him August 27, 1825. He brought back specimens of the "granite" from the summit, as well as the fine grained basalt used for the manufacture of adzes. James Jackson Jarves climbed to the summit in 1840, bringing back specimens of "augite, hornblende and olivine." He looked into Mokuaweoweo and reported that there were no signs of activity, not even ascending vapors. In the early part of January, 1841, Dr. Charles Pickering of the Wilkes Exploring Expedition, made the ascent and noted the same features mentioned by his predecessors, such as the ice and several cones of volcanic origin. In a desolate gravelly plain he found a few plants suggestive of a colder climate, probably the same that were brought back by Mr. Preston and named authoritatively, such as *Cystopteris fragilis, Trisetum glomeratum, Poa annua* and *Deschampsia australis.*

The following notes were made by me in 1886, when I made the ascent of this mountain in company with D. Howard Hitchcock, E. L. Gulick and Mr. Burt of Hilo. Reached Bougainville 900 feet above sea level the evening of June 18. This is a plantation belonging to Judge David Hitchcock, who cultivates many fruits, flowers and vegetables.

June 19. Left Bougainville at 5:30 A. M. Walked through the jungle—a fearful mass of mud too deep for safe riding. Proceeded up the flow of 1855 for fourteen miles and then veered over to the southeast slope of Mauna Kea, reaching a mountain house, Puakala, over 6,000 feet above the sea, constructed by Mr. Hitchcock. It is sixteen and a half miles in a direct line from Hilo, thirty-five by the road. Note that the lava has a greenish color, and that canyons begin to be conspicuous.

June 20. Spent Sunday in camp. The house is built of Koa wood.

June 21-22. Delayed by stormy weather for the start. The party killed three bullocks. The lava is partly compact with a micaceous mineral—partly vesicular and partly a breccia, covered

by reddish decayed volcanic ashes several feet thick, which were thought to correspond with the loess-like material seen at Hilo, and in Kau. Reached the summit later in the day. Counted twenty-three volcanic cones, mainly of lapilli, from the summit. The party somewhat affected by mountain sickness. Saw enormous lava bombs near the summit, made of solid olivine and white basalt. Can see into the crater of Mokuaweoweo. Returned to Puakala.

Satisfactory observations were taken with the pendulum and compared with those made at Hilo, Kalaioha, Waimea and Kawaihae. From the determination of the densities of a large collection of rocks gathered upon Mauna Kea and other localities upon the island, Mr. Preston estimates the mean specific gravity at 2.90. Assuming from the results of his calculations that the density of the earth is 1.77 times the density of the mountain, the mean specific gravity of the whole earth should be 5.13.

PUU WAAWAA.

When one is at the landing of Kawaihae, he may see a curious hill to the south at the base of Hualalai called Puu Waawaa. It is a fluted cone several hundred feet higher than its base which is 3,300 feet above sea level. The name in the Hawaiian language signified *fluted.* There are numerous ravines radiating from the summit penetrating the slopes for fifty or more feet, all of them apparently formed by the downward flowage of rain water. The material is tuff made of ash or fine gravel containing angular fragments—and it has the structure of the ordinary cinder cone, quaquaversal stratification.

This cone is not far removed from the Mauna Loa flow of 1859. There is a descent from it to the west of about 1,800 feet to another hill called Puu Anahulu and the slope is bordered on the east by a cliff facing the 1859 flow. This terraced slope has been covered by the lava from both Hualalai and Mauna Loa. Puu Waawaa has also been encircled by lavas from Hualalai which covered up the original floor between the two eminences. The fact of the more ancient age of these cones is very obvious to the observer upon the steamer going north from Kailua. He can see that lava of a darker color has flowed downwards around Puu Waawaa, proving that the fluted cone is older than the basaltic flows. Nor is the fluted character so obvious from the seaward side.

While this cone has arrested attention, Dr. Whitman Cross seems to have been the first scientific man to visit it, and he has

published his observations in the *Journal of Geology* No. 6, Vol. XII, October, 1904, entitled "An occurrence of trachyte on the Island of Hawaii." The terrace bench of Puu Anahulu he represents as made of an agglomerate aggregate of large and small fragments of a felsitic trachyte. The rock here has suffered decomposition by kaolinization. Both this original and decayed portion "exhibit a rude schistority due to a parallel arrangement of minute feldspar tablets, like that common in phonolite and some trachyte." The fragments at Puu Waawaa consist of brown pumice, dark aphanitic or black obsidian-like rocks, with some showing a mingling of the latter materials. The dark aphanitic fragments are not unlike some dense basalts of the island in appearance, yet resemble also the freshest rock from the boulders of Puu Anahulu. "Thin sections of the obsidian show it to be a colorless glass containing streams of feldspar microlites in some parts and free from them in others. The dull aphanitic streaks and masses are largely crystalline, with more or less of fine magnetic dust and ferritic globulites, and a colorless glassy base of variable amount." Chemical analyses of these rocks were made under Dr. Cross' directions by Dr. Hillebrand of the U. S. Geological Survey, and the surmise of their trachytoid character well substantiated. Further notices of the petrographic character are given in the Appendix.

The finding of lava rich in alkali feldspar, where heretofore only basalt and allied rocks had been noted, is a matter of great importance and Dr. Cross rightly assumes that there may have been quite extensive eruptions of these lavas, and that there is an ancient trachytic island here beneath the basaltic flows from the great volcanoes of Mauna Kea, Mauna Loa, and Hualalai; and that "if further exposures of the trachytoid rocks are found, it seems to me probable that they will be in the area of the Waimea plain, which extends practically from Puu Anahulu for twenty miles northeasterly to the north base of Mauna Kea, or in the northern and oldest basaltic section of the island, the Kohala mountains. The peculiar petrographic character of these rocks therefore substantiates the doctrine heretofore stated, of the greater age of the Kohala group of hills as indicated by the enormous erosion to which they have been subjected.

Mr. R. S. Hosmer informs me that there is an isolated area of dense forest just north of Keokeo in Kona. It should be examined so that it may be determined whether it is underlaid by older rocks or is a spared monument of a once more extensive woodland.

PART II

The History of the Exploration of Mauna Loa.

MAUNA LOA.

This term is applied to an immense dome seventy-four by fifty-three miles in its two diameters as measured at the sea level, and 13,650 feet in altitude. Its mass extends downwards more than 16,000 feet farther to the level of the submarine plain at the bottom of the sea upon which the whole Hawaiian Archipelago is situated. That would be a cone 30,000 feet in height and as much as a hundred miles wide within which are one or more conduits leading to the reservoir of lava which supplied the material for the various eruptions. It is probable that the cone may rest upon sediments of Tertiary age, like the sister island of Oahu.

The first word is equivalent to *Mount,* and the second signifies great or long. Some authors prefer to say Mount Loa rather than Mauna Loa. The natives call the caldera at the summit Mokuaweoweo. The great dome, so far as can be judged, is composed of overlapping sheets of basalt, both aa and pahoehoe. Those at the surface are of known age, or certainly younger than those that are deep seated. There are no large canyons upon its surface produced by the erosion of streams, because the deposition of the sheets is so recent. Above 10,000 feet there is scarcely any vegetation. The expanse is entirely composed of basalt showing evidences of many interlacing streams of lava. The surface is nearly level for the extent of four or five square miles.

Mr. Ellis who explored Hawaii in 1823 has nothing to say of Mokuaweoweo, while he writes fully of Kilauea. Pele is located definitely at Kilauea. I have not yet discovered any native traditions respecting eruptions from the larger volcano. It may be that the earlier explorers were not aware of the character of Mauna Loa. Ellis represents it as covered by snow throughout the year. It is uninhabitable, and therefore its eruptions would not usually be fraught with disaster to the inhabitants, and thus would be scarcely mentioned in the traditions. When Hawaii

PLATE 15.

View of Mauna Loa from near the Volcano House.

shall have been studied carefully it will be possible to give the sequence of several pre-historic eruptions. One of these is Keamoku, an expanse on the north side of the mountain adjacent to and underlying the flow of 1843. The fact that it is distinguished upon the Government map indicates that the surveyors were impressed by its recency. It starts from the cone of Kokoolau 8,000 feet high, and terminates at the altitude of 3,000 feet at the hill whose name is now applied distinctively to the flow itself. Its area is very much the same with that of the well known eruption of 1843, extending down hill for twenty-one miles, the first third of the way proceeding due north, and then to the northwest. The area of 1843 laps over the edge of Keamoku.

I find very nearly the same name applied to an aa flow on the opposite side of the mountain, along which the new Kau Volcano road runs for several miles. This is supposed to be connected with a broad stream starting just below Puu Ulaula seven miles east of Mokuaweoweo. Upon most of the maps this stream is represented to have the date of 1823, and to have been connected with the discharge from Kilauea of that date, described by Mr. Ellis. This gentleman, however, makes no allusion to the existence of any recent stream descending from Puu Ulaula in that year, nor does he have anything to say about eruptions from Mauna Loa. Our illustrations, Plates 14 and 26, will show the lack of connection between this early flow of aa and the eruption in Ponahohoa; and anyone who will take the pains to scrutinize this aa along the Kau Volcano road will be satisfied that it is much older than 1823. I have questioned Professor W. D. Alexander and Mr. W. E. Wall, the Government surveyors, upon whose maps this late date is given, and they do not recall their authority for this label. Hence I regard this flow as belonging to an unknown prehistoric date—but one of great importance.

EARLY HISTORIC ERUPTIONS.

The first considerable knowledge of the Hawaiian Islands was acquired by Captain Cook in 1778-9. From the narrative illustrative of this expedition I find the following description of the features of a part of Hawaii, which all who are familiar with the island will recognize as truthful.

"The[18] coasts of Kaoo present a prospect of the most horrid and dreary kind, the whole country appearing to have undergone a total change from the effects of some dreadful convulsion. The

[18] Capt. Cook's Voyage to the Pacific Ocean, Vol 3, by Captain Joseph King, LL.D., F.R.S., p. 104.

ground is everywhere covered with cinders, and intersected in many places with black streaks, which seem to mark the course of a lava that has flowed, not many ages back, from the mountain Roa to the shore. The southern promontory looks like the mere dregs of a volcano. The projecting headland is composed of broken and craggy rocks, piled irregularly on one another and terminating in sharp points."

THE FIRST KNOWN ATTEMPT TO ASCEND MAUNA LOA.

John Ledyard, the famous traveler, was one of the seamen of Captain Cook's party in 1779 when they were anchored off Kealakekua. I will quote the greater part of his narrative from *A Journal of Captain Cook's last voyage to the Pacific Ocean and in quest of a northwest passage between Asia and America.* Printed and sold by Nathaniel Patton, Hartford, Conn., 1783, p. 117.

On the 26th of January I sent a billet on board to Cook, desiring his permission to make an excursion into the interior parts of the country, proposing, if practicable, to reach the famous peak that terminated the height of the island. My proposal was not only granted, but promoted by Cook, who very much wanted some information respecting that part of the island, particularly the peak, the tip of which is generally covered with snow and had excited great curiosity. He desired the gunner of the Resolution, the botanist sent out by Mr. Banks and Mr. Simeon Woodruff, to be of the party. He also procured us some attendants among the natives to assist us in carrying our baggage and directing us through the woods. It required some prudence to make a good equipment for this tour, for though we had the full heat of a tropical sun near the margin of the island, we knew we should experience a different temperament in the air the higher we advanced towards the peak, and that the transition would be sudden, if not extreme. We therefore took each of us a woolen blanket, and in general made some alteration in our dress, and we each took a bottle of brandy. Among the natives who were to attend us was a young chief whose name was O'Crany and two youths from among the commonalty. Our course lay eastward and northward from the town, and about two o'clock in the afternoon we set out. When we had got without the town, we met an old acquaintance of mine (who ought indeed to have been mentioned before). He was a middle aged man, and belonged to the order of their Mida or priesthood, his name was Kunneava. We saluted each other, and the old man asked with

much impatient curiosity where we were going; when we had informed him he disapproved of our intention, told us that we could not go as far as we had proposed, and would have persuaded us to return; but finding we were determined in our resolves, he turned and accompanied us; about two miles without the town the land was level, and continued of one plain of little enclosures separated from each other by low broad walls. Whether this circumstance denoted separate property, or was done solely to dispense with the lava that overspread the surface of the country, and of which the walls were composed, I cannot say, but probably it denotes a distinct possession. Some of these fields were planted, and others by their appearance were left fallow. In some we saw the natives collecting the coarse grass that had grown upon it during the time it had lain unimproved, and burning it in detached heaps. The sweet potatoes are mostly raised here, and indeed are the principal object of their agriculture, but it requires an infinite deal of toil on account of the quantity of lava that remains on the land, notwithstanding what is used about the walls to come at the soil, and besides they have no implements of husbandry that we could make use of had the ground been free from the lava. If anything can recompense their labor it must be an exuberant soil, and a beneficent climate. We saw a few patches of sugar cane interspersed in moist places, which were but small. But the cane was the largest and as sweet as any we had ever seen; we also passed several groups of plantain trees.

These enclosed plantations extended about three miles from the town, near the back of which they commenced and were succeeded by what we called the open plantations. Here the land began to rise with a gentle ascent that continued about one mile, when it became abruptly steep. These were the plantations that contained the breadfruit trees. * * * * * *

After leaving the breadfruit forests we continued up the ascent to the distance of a mile and a half further, and found the land there covered with wild fern, among which our botanist found a new species. It was now near sundown, and being upon the skirts of these woods that so remarkably surrounded this island at a uniform distance of four or five miles from the shore, we concluded to halt, especially as there was a hut hard by that would afford us a better retreat during the night than what we might expect if we proceeded. When we reached the hut we found it inhabited by an elderly man, his wife and daughter, the emblem of innocent uninstructed beauty. They were somewhat discomposed at our appearance and equipment, and would have

left their house through fear had not the Indians (natives) who accompanied us persuaded them otherwise, and at last reconciled them to us. We sat down together before the door, and from the height of the situation we had a complete retrospective view of our route, of the town, of part of the bay and one of our ships, besides an extensive prospect on the ocean, and a distant view of three of the neighboring islands.

It was exquisitely entertaining. Nature had bestowed her graces with her usual negligent sublimity. The town of Kireekakooa and our ship in the bay created the contrast of art as well as the cultivated ground below, and as every object was partly a novelty it transported as well as convinced.

As we had proposed remaining at this hut the night, and being willing to preserve what provisions we had ready dressed, we purchased a little pig and had him dressed by our host who finding his account in his visitants bestirred himself and soon had it ready. After supper we had some of our brandy diluted with the mountain water, and we had so long been confined to the poor brackish water at the bay below that it was a kind of nectar to us. As soon as the sun set we found a considerable difference in the state of the air. At night a heavy dew fell and we felt it very chilly and had recourse to our blankets notwithstanding we were in the hut. The next morning when we came to enter the woods we found there had been a heavy rain though none of it had approached us notwithstanding we were within 200 yards of the skirts of the forest. And it seemed to be a matter of fact both from the information of the natives and our own observations that neither the rains or the dews descended lower than where the woods terminated, unless at the equinoxes or some periodical conjuncture, by which means the space between the woods and the shores were rendered warm and fit for the purposes of culture, and the sublimated vegetation of tropical productions. We traversed these woods by a compass keeping a direct course for the peak, and was so happy the first day as to find a foot-path that trended nearly our due course by which means we traveled by estimation about 15 miles, and though it was no extraordinary march had circumstances been different, yet as we found them, we thought it a very great one for it was not only exceedingly miry and rough but the way was mostly an ascent, and we had been unused to walking, and especially to carrying such loads as we had. Our Indian companions were much more fatigued than we were, though they had nothing to carry, and what displeased us very much would not carry anything. The occasional delays of our botanical researches de-

layed us something. The sun had not set when we halted yet meeting with a situation that pleased us, and not being limited as to time we spent the remaining part of the day as humour dictated, some botanizing and those who had fowling pieces with them in shooting; for my part I could not but think the present appearance of our encampment claimed a part of our attention, and therefore set about some alterations and amendments. It was the trunk of a tree that had fell by the side of the path and lay with one end transversely over another tree that had fallen before in an opposite direction, and as it measured 22 feet in circumference and lay 4 feet from the ground, it afforded very good shelter except at the sides which defect I supplied by large pieces of bark and a good quantity of boughs which rendered it very commodious, and we slept the night under it much better than we had done the preceding, notwithstanding there was a heavy dew and the air cold; the next morning we set out in good spirits hoping that day to reach the snowy peak, but we had not gone a mile forward before the path that had hitherto so much facilitated our progress began not only to take a direction southward of west but had been so little frequented as to be almost effaced. In this situation we consulted our Indian convoy, but to no purpose. We then advised among ourselves and at length concluded to proceed by the nearest rout without any beaten track, and went in this manner about 4 miles further finding the way even more steep and rough than we had yet experienced, but above all impeded by such impenetrable thickets as would render it impossible for us to proceed any further. We therefore abandoned our design and returning in our own track reached the retreat we had improved the last night, having been the whole day in walking about 10 miles, and had been very assiduous too. We found the country here as well as at the seashore universally overspread with lava, and also saw several subterranean excavations that had every appearance of past eruption and fire. * * * * * *

The next day about two o'clock in the afternoon we cleared the woods by our old rout, and by six o'clock reached the tents, having penetrated about 24 miles and we supposed within 11 of the peak. Our Indians were extremely fatigued though they had no baggage, and we were well convinced that though like the stag and the lion they appear fit for expedition and toil, yet like those animals they are fit for neither, while the humbly mule will persevere in both.

According to an attitude of the quadrant, the Peak of Owyhee is 35 miles distant from the surface of the water, and its

perpendicular elevation nearly 2 miles. The island is exactly 90 leagues in circumference, is very nearly of a circular form, and rises on all sides in a moderate and pretty uniform ascent from the water to the Peak, which is sharp and caped, as I have before observed, with snow, which seems to be a new circumstance, and among us not altogether accounted for. As a truth and a phenomenon in natural philosophy I leave it to the world. Owyhee has every appearance in nature to suppose it once to have been a volcano. Its height, magnitude, shape and perhaps its situation indicate not only that, but that its original formation was effected by such a cause. The eastern side of the island is one continued bed of lava from the summit to the sea, and under the sea is 50 fathoms water some distance from the shore; and this side of the island utterly barren and devoid of even a single shrub. But there is no tradition among the inhabitants of any such circumstance.

VANCOUVER'S EXPLORATION.

The next English expedition to the Hawaiian Islands after the death of Captain Cook was that commanded by George Vancouver in the year 1793-4, published in 1798. Vancouver had visited the islands before, having been connected with the staff of Captain Cook. King George the Third commissioned him to explore distant lands for a term of four years and to aid, so far as possible, in the improvement of the early nationalities. Thus he was the agent of the importation of domestic cattle into Hawaii. The Hawaiian King placed a *kapu*[14] upon them for ten years, which proved effectual for their continuance. At the present date it is possible to obtain descendants of these early cattle just as lions and elephants may be hunted in Africa. Sheep were also turned loose in the forests by Vancouver, but they did not survive long because they were hunted down by dogs. Other domestic animals that have reverted to the wild state are swine, horses, dogs, poultry and turkeys.

Upon the eleventh of January, 1794, Vancouver observed columns of smoke arising from Kilauea, which were recognized as volcanic exhalations. After reaching the anchorage of Karakakooa parties were organized to explore the interior, under the direction of Archibald Menzies, the distinguished botanist. They first ascended Hualalai, or *Worroway,* which they found to be a

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[14] The early spelling of this word is *Taboo*, whence it has been incorporated into our speech. When the native pronunciation became better understood *Taboo* became *Kapu*.

volcano over 8,000 feet high, with several small well defined craters upon its summit, which were figured in the narrative. A second trip penetrated the forest between Hualalai and Mauna Loa for a distance of sixteen miles.[15] Finally the successful attempt was made to ascend Mauna Loa. Vancouver did not present the results of this trip in his narrative, for some unexplained reason. Being fully persuaded that the manuscript account of this exploration must be in existence, I authorized Dr. Henry Woodward, the well known English geologist, to search for it in London, and through his efforts have come into possession of a copy. Because of its great value as a record of the first attempt to climb this mountain by Europeans, and of the condition of the volcano at that time, it is herewith presented in full.

ARCHIBALD MENZIES' JOURNAL.

Feb. 5, 1794. Having by the fifth finished the letters and packages for England, and delivered them to Capt. Vancouver to be forwarded in the "Doedalus" store ship which was on the point of sailing for New South Wales, I was desirous of making another attempt to gain the summit of Mownaroa: for this purpose I consulted with Tamaikamaika not only on the means but likewise on the best route for accomplishing such an object; when he assured me that the most likely way of succeeding was to ascend it from the South side of the Island, to which I must go by water in one of his canoes, and that he should take care to send with me a Chief well acquainted with the proper route, who should possess proper authority to protect me from any ill-usage in the journey and have ample power to procure provisions, attendants, or whatever else should be found necessary to accomplish so arduous an undertaking. With such flattering attention from the King, and such prospect as he represented of succeeding, I readily accepted his generous offer and cheerfully consigned myself to the care and guidance of Rookea the Chief whom he now appointed to conduct the Expedition, and to whom he delivered the strictest injunctions respecting his charge: the business being thus settled we prepared for our departure on the following day: in the meantime Lieut. Baker and Mr. McKenzie of 'The Discovery' and Mr. Haddington of 'The Chatham' expressed their desire of accompanying us and obtained leave from their Commanders to share in the pleasures as well as in the fatigues and hardships of this enterprise.

[15] Printed for the first time in Thrum's Annual for 1908.

Feb. 6th. Being all equipped we set out from the vessels in the afternoon of the 6th of February, with the Chief and about 20 paddlers, in a large double canoe belonging to the King, and before we left the Bay we were join'd by Mr. Howell who was to accompany us in another double canoe, with his own attendants.

We now proceeded along the shore to the southward for about four miles from Karakakooa, when we came to the Village of Haunanow, where we landed for the night. We expressed our desire of going further on but the Chief told us that there was not a place at the next village sufficient to accommodate so large a party, for which reason he wished us to remain here all night.

7th. Next day we embarked again, by day-light, in the two canoes and got but a short distance when we came opposite to a small village where the Chief wanted us to land to breakfast, but this we overrul'd by declaring that we were not hungry as we wished to get on as far as we could in the cool of the morning: the next stage was, however, such a long one that we afterwards regretted not having taken his advice, for the coast was dreary and rocky and the shore so steep and rugged that we found no place where we could land till it was near noon, when we entered a small bay surrounded at the bottom by a sandy beach and groves of Cocoa Palm Trees well croppd with fruit: here we landed at a small village called Honomazino where the King ordered us to be supplied with a stock of Cocoa-Nuts for our journey, and upwards of 200 of them were packed up for that purpose, the greatest part of which were sent on men's backs across the side of the mountain to meet us in our ascent on the other side.

After refreshing and resting ourselves in the heat of the day we were anxious to proceed again in the cool of the evening but the natives informed us that there was too much wind to get around the next point with the canoes, so that we were obliged to remain here for the night.

The country round us at this place was so rugged, dreary and barren, that the natives were obliged to depend a good deal upon the sea for their sustenance. When the fishing canoes came into the Bay in the evening we had an opportunity of observing their manner of traffic with one another as the whole village, and people even from other villages flocked about them and a brisk market was kept up till they disposed of all their fish for small nails and bits of iron and sometimes we observed that they drove very hard bargains. Of these nails the fishermen make their fish-hooks and no doubt are obliged, in their turn, to purchase potatoes, yams, cloth, &c from the Planters; thus we find that nails and bits of iron here answer all the purposes of money and circu-

late amongst the natives in the same way that gold and silver does with us.

The coast here is composed of huge masses of rocky lava so porous and cavernous that the sea pervades it and renders all the springs of water in the low ground and about the villages brakish, that we were obliged to send 4 or 5 miles up the country for good water, yet such is the force of habit that the natives could use this brakish water very freely.

8th. At 8 next morning I observed the Barometer at high water mark where I found the Mercury stood at 30in 15pts and the Thermometer was, at the same time, 74°.

Before I left the 'Discovery' I compared my Barometer with the Marine Barometer on board and found them to agree in height pretty nearly; it was therefore settled on to register the height of the Marine Barometer in Karakakooa Bay every two hours between eight in the morning and six the evening, daily, during my absence, and at one or other of these hours I was to make my observations at the different stations on the Mountain, and by taking afterwards the difference of the corresponding observations made at the same instant of time, the result would certainly prove more accurate than the mode I adopted in my former journey, more especially in case of any particular change of weather taking place while we were ascending the Mountain.

After the whole party had breakfasted we left Honomazino in our canoes about nine in the morning and soon after passed the western part of the Island which is a dreary tract of the most rugged rocks of lava scattered here and there with some fishermen's huts. About noon we came to a small village named Manaka where found our Chief Rookea's residence and where we landed before his house at a small gape between rugged precipices against which the surges dashed and broke with such violence and agitation and with such horrific appearance, that even the idea of attempting it chilled us with the utmost dread. We, however, quietly submitted ourselves to their guidance and were highly pleased to see the extraordinary dexterity with which they managed this landing. Having placed their canoe in readiness before the gape they watched attentively for a particular surge which they knew would spend itself or be overcome in the recoil of the preceding surges before it could reach the rocks, and with this surge they dashed in, landed us upon a rock from which we scrambled up the precipice and in an instant about 50 or 60 of the natives at the word of command shouldered the canoe with everything in her, and clambering up the rugged steep, lodged her safely in a large Canoe-House upon the brink of the precipice,

to our utmost astonishment. The other canoe was landed in the same manner, and as the Chief had some arrangements to make, we were obliged, in compliance with his request to remain at this dreary-looking place all night, and a situation more barren and rugged can scarcely be imagined. The kind civilities and good treatment received from the natives were, however, unremitting, and here, as if to make amends for the dreariness of the situation, they particularly exerted themselves by every means in their power to amuse and entertain us. The Chief and his people were equally eager and attentive in doing little acts of kindness and thereby assiduously displaying their unbounded hospitality.

On seeing near this village a large pile of stones built regularly up in a square form on the brink of the shore, curiosity prompted us to enquire what was the intent of it, when they informed us that it was erected to mark out the limits between the two districts of Akona and Kaoo, by which we found out that we had now reached the southern limits of Akona.

In the afternoon our attention was at one time directed to a number of young women who stripped themselves quite naked upon the summit of a pending cliff, and taking a short run vaulted one after another from the brink of it headlong into the sea, regardless of the foamed and agitated appearance of that element, and as it were setting its wildest commotions at defiance, for at this time the surf ran very high and dashed with furious force against the cliff, yet they dexterously disentangled themselves, and clambering up the rock again, repeated their leaps several times with seeming satisfaction till they were quite fatigued. The cliff was at least thirty feet high and so very rugged with packed rocks which were now and then deluged with a boisterous surf, that to look down the precipice was enough to intimidate any one not accustomed to such extraordinary feats of activity.

The Chief here packed up a quantity of dried fish to be carried with us, and presented each of us with a mat and a quantity of Island Cloth to lay on at night during our journey.

9th. After an early breakfast on the morning of the 9th we were again launched in our canoes and proceeded to the Southward, keeping close along shore within the recoil of the surges where, tho the water is much agitated they conceive less danger of swamping as their canoes are much more lively upon it than much further out at sea; yet, notwithstanding our great confidence in their dexterity and management, we could hardly divest our minds of the idea of danger when beholding every moment the boisterous surges dashing with such furious violence against the rugged and cavernous cliffs high over our

heads and threatening us, as it were, every instant with overwhelming destruction, nor were the appearances of the surges breaking on the other side of us at times less awfull, as they threatened to deluge and waft us, in their foaming course towards the rocks. We, however, got through this wild navigation with no other inconvenience than that of our apprehensions, and getting all very wet.

This part of the coast is a dreary rugged tract composed of black porous rock of lava forming here and there grotesque arches, vaults and deep caverns into which the sea pushes by the violence and agitation of the waves with great force and frequently gushes up again several yards inland through chinks and crevices with a hissing noise, into the form of fountains which in the sunshine reflect all the colours of the rainbow. These often rivetted our attention as we went along and made us forget our own danger in admiring their beautiful and picturesque appearances.

We at last prevailed on them to quit the windings of the Shore where we were under so much dread, and steer a straighter course across some small bays none of which appeared fit for anchorage, from their being too much exposed, and early in the afternoon we landed at a small village called Pateence near the South point of the Island. We took up our abode in a house belonging to Cavahero, and they told us that the village, which consisted only of a few fishermen's huts, belong to Namahanna, Teamottoo's wife. The country between this and Manaka, the place we left in the morning, is one continued tract of loose, rough and picked lava, the most dreary and barren that can possibly be conceived, so that it would be a tedious and fatiguing journey to come from thence by land and such as even the natives themselves seldom attempt, for when they wish to visit the south side of the Island they generally come thus far in canoes from the west side, and leave them here till they return again, so that this forms a common port at which there were several arrivals to and fro in the course of the evening.

Our Chief advised us to remain here all night and as we knew so little of the country we were obliged to be entirely under his controul. The afternoon was spent in covering up our canoes upon the beach, to preserve them from the sultry weather, and in preparing everything for our land expedition which was to commence the next morning. From hence we had a full view of the snowy summit of the mountain which shewd a remarkable glaring lustre from the sun's reflection. Some of the party that were despatched across the country from Honomazino met us with Cocoa Nuts.

10th. After giving our several attendants strict charge of their respective burthens we left our canoes at Pateence and set out early on the morning of the 10th to prosecute the remainder of our journey by land. We had not travelled far when we found we had to ascend an elevated, steep, rugged, bank that took its rise at the south point of the Island and running along the southern side of Pateence Bay continued its direction inland behind the village: on gaining its summit, which was not an easy task, an extensive tract of the most luxurious pasture we had yet seen amongst these Islands rushed at once upon our sight, extending itself from the South point to a considerable distance inland: it was croppd with fine soft grass reaching up to our knees and naturally of a thick bottom that would afford excellent feeding for cattle where herds of them might live at their ease, if it was not for the scarcity of fresh water which we experienced in all the low grounds we had yet visited.

From the summit of this bank we pursued a path leading to the upper Plantations in a direct line towards Mownaroa, and as we advanced the natives pointed out to us, on both sides of our path, places where battles and skirmishes were fought in the late civil wars between the adherents of the present King and the party of Kaooa, the son of the late Tereoboo who was King of the Island in Capt. Cook's time. Tamaika-maika's warriors were headed by Tianna who at that time made use of fire-arms which obliged Kaooa's warriors to intrench themselves by digging small holes in the ground into which they squatted flat down at the flash of the muskets; many of these little intrenchments are still very conspicuous and they were pointed out to us by the natives with seeming satisfaction, as it was to them a new mode of eluding the destructive powers of firearms on plain ground. Here, then, we behold the first beginnings of fortification amongst these people, which they probably never thought of till these arms were introduced amongst them ,and we also see that the same mode of fighting naturally begets the same mode of defence in every part of the world. It was in these Wars that Tianna, by his knowledge of fire-arms gained so much ascendancy on the Island and became so powerful a Chief. We continued our ascent through a rich tract of land which appeared to have laid fallow or neglected ever since these wars, till we came to a grove of the Dooe Dooe tree and under their shade we stopped to rest and refresh ourselves, in the heat of the day. Close by us was a fine Plantation, belonging to Tamaika Maika, called Tahookoo where our Purveyor was particularly ordered to demand supplies for our journey, which he did, and only received one small Hog. This,

however, did not come to our knowledge till after we had passed it, and when the Chief told me of it I made a show of noting it down in my little Memorandum Book in order to make it known to the King: this had the desired effect for it instantly spread through the crowd and from them to the Steward of the Plantation, whom we found extremely assiduous in supplying our wants on our return.

In the afternoon we resumed our journey, and soon after reached the upper Plantations, where instead of ascending directly up the Mountain as we expected, they led us across these Plantations, to the North Eastward at a distance of 5 or 6 miles from the shore, by a narrow winding path which in some places was very rugged, and seldom admitted more than one person at a time, so that we followed one another in a string and occupied a considerable space in length from the number of our own party and the crowds that followed us from village to village through curiosity and flocked to see us from far and near: this path we found to be the public road leading to the East end of the Island, and on the small eminences here and there we met cleard spots for resting on, where the wearied travelers generally set down to chew sugar-cane and admire the surrounding prospect.

Towards evening we descended into a fine fertile valley, and put up for the night at a village called Keeoraka on a rich Plantation belong to Cavahero, and we computed that we had this day travelled 18 or 20 miles, though we did not seem to be much more than half way that distance, in a straight line from where we set out in the morning, the path was so circuitous and winding, and we observed that a great deal of ground on both sides of our path lay waste, which appeared to have been cultivated not many years ago. This we ascribed to the late commotions on this part of the Island, as it is the common custom of these people to destroy the Plantations of the vanquished.

When we stoppd in the evening we were surrounded by such a concourse of people who pressd so close upon us that we could scarcely stir. Rookea, observing our situation, took a stick in his hand and soon cleard a circle for us: he afterwards Tabood a large house for us and seemed to manage the natives with great authority. This was by far the most populous village we had yet met with since we left Karakakooa. Towards the dusk of the evening there fell some showers of rain which gave a gay and refreshing look to the most enchanting scenes of rural industry with which we were surrounded. The economy with which these people laid out and managed their ground, and the neatness with which they cultivated their little fields, made the whole Valley

appear more like a rich garden than a Plantation: a stream of water which fell from the Mountain through the middle of it was ingeniously branchd off, on each side, to flood and fertilize the most distant fields at pleasure.

11th. We set out early on the morning of the 11th and ascended a steep verdant hill on the Eastern side of the Valley, from the summit of which we had a charming prospect of the country for a long way before us, presenting extensive and rich plantations industriously cultivated: as we passed on through them the natives pointed out one which they said the King had given to Tooworero soon after we left him on the Island: this was further confirmed to us by the vassals on it readily owning Tooworero as their Chief. We found the people everywhere busily employed in their little fields many of which were here croppd with Plantains and Bananas which had a ragged appearance from having little or no shelter, yet they bore fruit tolerably well. We seldom observed these vegetables cultivated so low down on the Western side of the Island where they generally occupy the verge of the Forest, a situation which for shelter, seems more congenial to their tender foliage. We observed here that they suffer many of their fields here and there to lay fallow and these, in general, were croppd with fine grass which they cut down for the purpose of covering their new planted fields of Taro or Yams, to preserve them from the powerfull heat of the sun.

After crossing these Plantations we came to a barren woody tract, without even a Hut or the least arable land for a considerable distance, and so arid that we could get no water to quench our thirst or refresh ourselves: this made us quite out of humour with our guides as the day was far advanced before we could get any breakfast, and by the time we got through this dreary tract we were ready to drop with hunger and fatigue.

At last we came to a romantic situation where there were a few huts on the verge of the forests: here under a small shade they spread a mat for us on which we threw ourselves down to rest till some refreshments were got ready and till the heat of the day was partly over. After taking our meal the Priests consecrated our shade by planting Taboo sticks round it, on account of our eating Pork, Cocoa Nuts and other prohibited provisions in it: this deprived us entirely of the society of the ladies, for though they set down on our mat before breakfast and were very chatty and cheering, yet nothing would induce them to approach it after their rods were stuck up: such is the powerfull influence of priestcraft amongst these people.

In the afternoon we continued our journey by the same path

which still led along the upper Plantations, preserving nearly the same distance from the sea-coast, and was excessively rugged and woody, with here and there some intervening plantations arranged alternatively with these rugged forests which seemed to mark the latter courses of the Lava down the side of the Mountain. We stopped in the evening at a Plantation belonging to Tamaika-maika, called Poonaroo.

12th. Next day we continued our journey through the same kind of picturesque country, and soon after setting out from Poo-naroo we crossed a Plantation belonging to Trailooevee the Chief whose hand had been so badly wounded at Karakakooa before we came away, and the following circumstances will show the good-ness of his heart and how thankfull he was for our attention towards him on that occasion. He had, it seems, sent before us particular orders for his Steward to wait upon us as we passed and make an offer of whatever his Plantation produced. The Steward executed his Master's mandate in the most friendly man-ner, and even pressed us with tears of gratitude in his eyes, to accept something, as otherwise his Master would think that he had not done his duty. This induced us to take a few things from him, after which we assured him that if we should stand in need of a further supply we would send back to him for it, with which he appeared quite satisfied. Little acts of hospitality and kindness are acceptable in all places and on all occasions, but nowhere more particularly so than to the way-worn travellers in remote regions and amongst uncivilized tribes where those little civilities may be considered as the spontaneous offerings of the heart and cannot fail to touch the feelings of those on whom they are conferred, with a more than common sense of gratitude and admiration.

Though we had much reason to be satisfied every step we went with the kind attentions and unbounded hospitality of the natives, yet we could not help being now a little out of temper with them at the great distance they were taking us, as it were, round the foot of the mountain till, in the afternoon we reached a fine Plantation, called Tepapala, belonging to the King, from which, they told us, we were to ascend the Mountain, and as the Chief had here to provide his last supplies of provisions for our journey up we were obliged to stop for the night, to allow him time for that purpose.

In the evening we sent back one of the natives to Karakakooa with a note to Capt. Vancouver, to relieve any anxiety he might be under respecting us and to acquaint him with the distance we

had come and the probable time it would still take us to accomplish our object.

We were now within a few miles of the Volcano of which there seemed to be, this day, a considerable eruption, and as the wind blew from that direction, the smoke dust and ashes arising from it proved very troublesome to our eyes in travelling with our faces towards it.

13th. Before we set out on the morning of the 13th I observed the Barometer at eight, when the Mercury stood at 28in 20pts, which made our height at this place 1800 feet above the level of the sea. The Thermometer was, at the same time, 67°.

After breakfast, everything being got ready, and the party arranged, we continued our march through the Plantation for two or three miles further and then began our ascent up the South East side of Mauna-roa, in an easy slanting direction, passing through groves of trees and clear spots, alternately, by a narrow rugged path without meeting any more cultivated ground, after we quitted the Plantation of Tepapala, or any houses till, towards sun-set, when we came to two or three old huts where our guides told us we must encamp for the night. The Chief no longer depended on his own knowledge of the path but brought men with him from the last Plantation to conduct the whole party up the Mountain which now lay between us and Karakakooa: we had the Volcano to our right most part of this day and in the forenoon the smoke and ashes arising from it made the air very thick, which at times proved very tormenting to our eyes.

At sun-set the Thermometer was at 54° and the Barometer stood at 26in 50pts which made our height from the sea 3510 feet.

14th. At sun-rise next morning the Thermometer was so low as 41°, which was lower by two degrees than we found it near the upper edge of the wood on Whararai at the same time of the day, and yet we were not here advanced half way up the woody region of the Mountain. Whether this diffusion of cold much lower down be owing to there being but little wood on this side of the mountain or to its being a much greater body than Whararai, I cannot take upon me to say, as I have not sufficient data to determine, but the air was at this time so chilly, and the natives complained so much of the cold that we did not stir from the place of our encampment till after breakfast when we again set forward up the Mountain in a reversed oblique direction to what we came the day before, but in so winding and circuitous a manner, and through such pathless and rugged tracts, avoiding the clumps of forests here and there, that had we not had good guides with us we should have met with insurmountable difficulties.

We had sight now and then of the lower edge of the snow which did not appear to be far above us: we therefore began to entertain the most sanguine hopes of reaching it at least, should we not be able to accomplish the full extent of our object in getting to the summit. In the afternoon we turned our faces more directly up the mountain when we found the ascent very steep and rugged and consequently more fatiguing. Towards evening we reached the upper verge of the forest, nearly over Tepapala, where we encamped for the conveniency of having wood at hand to burn and erect our huts with. The natives having pitched upon a clear spot overgrown only with strong tall grass, they all set to work, and in the course of about two hours erected a small village of huts sufficient to shelter themselves and us comfortably for the night. These huts tho' finished with such hurry were neatly constructed and well thatched all over with long grass: a large one was built in the middle of the village for us to eat and set in, besides a small one for each of us to sleep in, where they spread our bedding on a thick layer of long grass, so that we enjoyed our repose comfortably as we could wish.

While this business was going forward one of the gentlemen laying down his knife carelessly had it stole from him: this was made known to Rookea, who immediately caused diligent search to be made for it and made such a stir about it amongst the whole party that it was soon found again, and one of the strangers who followed us up was suspected of having conceald it, for which the Chief was in such a rage at him, for this act of dishonesty that he would certaintly have put an end to his existence, on the spot; by plunging the knife into his body, had we not interfered at the moment he had his hand lifted over him to commit the horrid deed: he then peremptorily ordered him to quit the encampment and not to show his face again amongst the party.

This was the only instance of an attempt to pilfer from us the least article during the whole journey, though we were often surrounded by immense crowds, and even at this time, what with men and women who followed us up the mountain through curiosity, and our own attendants, who carried bedding, water, and provisions of every kind for themselves and us we were very little short of a hundred people in the party.

In this day's march we saw many strange-looking plants different from any we had before observed, but very few of them being in either flower or seed it was not possible to make out what they were. Near our encampment I found a large beautiful species of Vicia clambering up amongst the thickets in full bloom.

Being now at the upper edge of the forest I observed the Barometer at six in the evening, when it stood at 23in 73pts which is equal to 6500 ft. in altitude, and this may be considered as the height at which the wood ceases to grow upon this immense mountain. The Thermometer, observed at the same time, was at 41°, and as we had heated ourselves a good deal in this day's march up the mountain we felt the air after sunset remarkably chilly and cold, which induced us to keep large fires burning near our huts during the whole night: notwithstanding this precaution many of the natives were so restless with the cold & continued coughing that they enjoyed very little repose, and not indeed without cause, for when we got up next morning the Thermometer was at 28° and the grass which grew about our huts was so stiff and whitened by hoar frost, and the earth that was anywise moist or swampy was encrusted with icy concretions about our encampment.

The frost, therefore, must have been keen during the night time, and from this circumstance I think we may consider the upper edge of the wood as the lower line of congelation upon this mountain, but meeting with it so low down as we here did, and that, too, on a tropical mountain, so closely surrounded by the mild temperature of the sea-air, will no doubt stagger the belief of those who have been led to consider the lower line of congelation within the tropics as having a much greater altitude even in continental regions which are always allowed to be colder than Islands of moderate size.

15th. The natives, who were all bare-footed, could not stir out of their huts in the morning, until after breakfast when the cheering influence of the sun dispersed the frost, but they greatly dreaded its consequences higher up the mountain, where they said the cold was so intense that it would certainly kill us and them too, and they described its effects by contracting and shivering themselves and cautioned us very strongly against going higher up or exposing ourselves and them to such danger: even the old Chief Rookea was so strongly prepossessed of this opinion that he now entreated us in the most earnest manner to relinquish the idea of going higher, for that he and several others were already nearly overcome with the fatigue of the journey, and that the cold on the mountain would kill them. We endeavored to sooth their minds by promising them that we should not attempt to go higher up than the edge of the snow which we did not conceive to be far from us, and after accomplishing that, which we should undoubtedly be able to do, in the heat of the day, we should return again to the encampment in the evening. They appeared

so far satisfied with this declaration that we set out after breakfast, followed by the whole party, in a direct line up the mountain, but we soon found that many of them came on so slow and reluctantly that about ten in the forenoon we proposed to the Chief that he and most of the party should return back and encamp on the edge of the forest whilst we should go on with the guides and a few stout volunteers of the natives to carry some little refreshment and some of our bedding to wrap round us and them in case the cold should be found too powerfull to withstand. The Chief, finding his former entreaties of no avail, readily agreed to this proposal, and parted with us with tears in his eyes, after he and our guides had fixed upon the place where they were to wait for our return.

Having made this arrangement we continued our progress up the rugged steep which now became naked, dreary, and barren, with only here and there little tufts of grass in the crevises of the rocks: by noon finding that vegetation had entirely ceased, not a blade of grass, moss, or even lichen was to be seen anywhere around us for some time, I observed the Barometer to ascertain our height, when I found it was 20in 55pts which is equal to 10543 feet above the level of the sea, so that this may be considered as the upper line of vegetation, or rather a little above it, on this mountain, but whether this was occasioned by the want of soil of which there was nothing but volcanic dreggs, or the particular rarefaction and temperature of the air at this height being inimical to vegetation, I cannot take upon me to say, though the latter, I think, is most probable.

While we were resting and refreshing ourselves after making these observations, one of the natives, who struggled higher up the mountain, came running back to us with snow in his hand, and though we were much fatigued, for the ascent was very steep, yet this gave us fresh encouragement and we continued to ascend till we passed several patches of snow, when in the evening, finding that we were not likely to gain the summit of the mountain with daylight, for every height seemed lengthening as we went on, we did not conceive it prudent to go far into the snow and therefore stopd short to consult with one another on what was to be done, whether we should go back to the encampment for the night and come up next day better provided, or whether we should venture to remain where we were all night, at the mercy of the weather on the bleak slope of this immense mountain, and on the small pittance of provisions we had with us? Everyone was so fatigued with this day's journey, for we made uncommon exertions in the expectation of gaining our object, that the dread

of descending and ascending again such a rugged steep made us, at all hazards, prefer the latter.

At this time one of the gentlemen, Mr. Haddington, who went higher up amongst the snow, accompanied by one of the natives, in expectation of reaching the summit, returned to us so overpowerd with fatigue that he was taken very ill: in this state we dreaded the consequence of his remaining with us all night, and after giving him some little refreshment, we sent him off before he coold or stiffend with the cold, to the encampment, attended by two of the natives, and we were happy afterwards to find that he reached it in due time, and fortunately recovered.

As we had now taken up our abode at the lower edge of the snow I observed the Barometer at six in the evening, when it stood at 19in 80pts which in altitude is equal to 11515 feet, and the Thermometer at the same time was at 33°.

We were not, as might naturally be expected, at this time, without our apprehensions that our constitutions which were for some time inurd to the searching heats of a tropical climate below, would be greatly affected by this sudden transition to the upper snowy region of the Mountain, for since we began our ascent we may be said to have gone through all the variety of climates between the Equator and the Pole. We quitted the tropical plantations below and came through the vast forest which surrounds the middle region of the Mountain and which may justly be considered as its temperate zone, and now we are stationed for the night within the verge of the frigid zone of this immense peak, which in this way may be aptly compared to one of our Hemispheres, and yet, after all, we were so inconsiderate of our own safety as not to make any particular provision of warm clothing to prevent the banefull effects of this sudden change: it happened, however, very fortunate that the weather proved mild and favourable all the while, so that we did not suffer so much inconvenience by this quick transition from the tropical regions to this frigid zone as might be apprehended.

After the excessive perspiration we underwent in this fatiguing day's journey, clambering up a steep rugged ascent wholly exposed to the influence of the sun in the heat of the day, it was necessary to take every precaution in our power to prevent numbness and stiffness of our limbs by exercise and continually moving about to keep ourselves warm, for we had nothing here wherewith we could keep up a fire, and all the provisions we had remaining was a small quantity of chocolate, a few ship's biscuits and near a quart of rum, together with a few Cocoa Nuts: of these articles we carefully preserved the best half for next day,

and divided the other half as equal as we could amongst the party which was now about a dozen in number. We managed to boil the chocolate in a tin pot over a small fire made of our walking sticks, and each had his share of it warm, with a small quantity of rum in it, before he went to bed. We had no other water than what we melted from the snow, which we thought greatly improvd the chocolate.

For our bed we made choice of a flat even rock on which we could all huddle close together, and after marking out the exact space we should occupy, of it, we raised a small parapet round it, with the Lava, to break off the wind which after sunset blew very keen and penetrating: all the bed clothes we hitherto required were a few folds of the Sandwich Island Cloth over us, with a mat under us which was found sufficiently comfortable in the lower regions, but this night, after spreading a mat on the bare rock, as it was agreed we should all sleep together to keep ourselves warm, we joined together everything we had for a general covering, made pillows of the hard lava, and in this was passed the night, tolerably comfortable, though we could not sleep much, nor was it indeed to be expected. At this time, so many thousand feet high, reclined on the hard rock for our bed, with no other shelter than the grand canopy of heaven our minds were variously occupied, sometimes in meditating on the dreadful consequences of a snowstorm coming on whilst we were thus situated: at other times in contemplating the awfull & extended scene around us where the most profound stillness subsisted the whole night, not even interrupted by the least chirp of a bird or an insect. The moon rose out of the sea at an immense distance and her orb appeared uncommonly large and brilliant, and the sky being perfectly clear overhead, the assemblage of stars appeard very numerous and shone with unusual brightness. These led the imagination to the utmost stretch and afforded objects of both wonder and admiration.

16th. Next morning, at sun-rise, the Thermometer was at 26° and the air was excessively keen and piercing: we made a scanty meal on the remainder of our provision, before we set out, but for want of fuel, had the greatest difficulty in getting our chocolate boiled, though we burnt mats and everything we could think of. Those of the natives who appeared less able to withstand the cold or further fatigue were sent down to the Encampment, and at the same time we set forward with the rest of them, up the Mountain, carrying with us the remainder of the liquor and a few Cocoa Nuts as our only resource of refreshment in case of emergencies. As we went on we soon found the ascent become less steep and

everywhere chequered over with large patches of snow which was so hard that we walked over it with ease, and we marched a pretty quick pace to keep ourselves warm. We found the summit of the mountain nearly flat for several miles, strewd over with huge lumps of loose lava, and here and there deep snow. About 11 in the forenoon we arrived at the mouth of an immense crater at least three miles in circumference, and looking round us we conceived the western edge of it to be the highest part of the mountain. I was therefore desirous to make that the place of observation with the Barometer, but being on the south side of the crater, to get to this eminence we had to cross over a large hollow full of hideous chinks and chasms in all directions, and strewd over with large masses of broken and peeked lava in irregular piles, exhibiting the most rugged and disruptive appearance that can possibly be conceived. Mr. Howell's shoes being already cut and torn in pieces with the lava, and his strength being much exhausted with fatigue, he declined attempting this dreadful place: we therefore left him and the natives on the South side of it, to wait our return, while Mr. Baker, Mr. McKenzie, and myself, and the servant who carried the Barometer, crossed over this rugged hollow after a hard and persevering struggle, and by noon got to the highest part of the mountain, on the western brink of the great crater, where I observed the Barometer and found the Quicksilver stood at 18in 40 pts, and that on board 'The Discovery' at Karakakooa Bay, observed at the same instant of time, was found to be in 30in 16pts so that the difference is 11in 76pts, which will make the height of this immense mountain 13,634 feet above the level of the sea; but it is necessary to observe that the correction for the temperature of the atmosphere has not been allowed for in this calculation nor at any other station upon the mountain, which will make some difference in the result of the observations. The Thermometer here was at 62°.[16] Mowna-Kaah bore by compass North by East of us; Highland of Wowee North West by North; and Whararai, which appeared under us like a hilloc, bore North West by West. I regretted much not having a spirit-level or some other instrument to ascertain whether this mountain or Mowna-Kaah is the highest, though from the Peak of the latter being at

[16] As nearly as can be estimated the difference in temperature between the top of the mountain and the ship was thirty degrees. This would make it necessary to reduce the figure given by Menzies by seventy feet; making the true altitude 13,564 feet. Wilkes' determination was 13,750; J. M. Alexander's in 1885, 13,675.

this time more whitened over with snow, I am inclined to think it would have the pre-eminence in this respect, to Mowna-roa. The sides of the Crater (which was, as near as we could guess, about a mile in diameter), were quite perpendicular and, as we conjectured, about 400 yards in height, all around, excepting opposite to the hollow already mentioned, where the height was much less: the bottom of it was quite flat, being filled up with lava with a wavy roughness on its surface, apparently in the state in which it coold in this immense furnace. At the edge of it we observed some smoke in two or three places which we conceived to issue from hot springs, as on our way back to the party we visited the entrance to a cavern out of which there issued a very hot stream. In undergoing our struggle again across the rugged hollow we all felt less or more exhausted with fatigue, but Mr. Baker in particular became so weak and faint, that we were obliged to stop for him two or three times till he recovered his strength, and when we came back to the place where we left Mr. Howell and the natives, we found only two of the latter in waiting for us, faithful (poor fellows) to their trust, though shivering with the cold at the risque of their lives, and patiently enduring the pangs of both hunger and thirst; but when they informed us that Mr. Howell and the rest of the natives had gone off for the encampment, and had carried away with them the small quantity of liquor which we had carefully preservd for emergencies, it sounded like the knell of death in our eyes, and we could not help blaming Mr. Howell for thus deserting us; but the absence of our cordial, on which we had built our only hope of cheering comfort to enable us to go through the long journey still before us afflicted us most: thus overwhelmed, spiritless & faint, we threw ourselves down upon the bare rocks and for some moments revolved our melancholy situation in silence. The distance we were from the party, which was considerably more than half the height of the mountain; the ruggedness and steepness of the declivity; and our weakness and inability to undergo fatigue without some miraculous support, all obtruded themselves on our minds in the most gastly shapes. On further enquiry we found that our trusty friends had still a reserve of three Cocoa Nuts: the liquor of these we gradually sipt and it greatly revivd us, and after eating some of the kernels which were carefully divided amongst us, we set out on our return to the encampment where we were so fortunate as to arrive safe at ten at night, after the most persevering and hazardous struggle that can possibly be conceived.

OTHER STATEMENTS.

The natives of Captain Wilkes' party in 1841 stated that there had been an eruption from the north Pohaku o Hanalei sixty years earlier, or about 1780. This accords with the specific statement of Keaweehu the bird catcher and guide who said there had been an eruption upon the mountain shortly after the death of Captain Cook.

John Turnbull in his narrative of a voyage around the world from 1800 to 1804, says that as he was leaving Karakakooa, January 21, 1803, he had a full view of some eruptions from the volcanic center of the island of Owhyhee. This must have been upon the west or north side of Mokuaweoweo. He adds that "many parts of the surface of the island are covered with lava, calcined stones, black dust and ashes emitted by former eruptions."

An indefinite statement was made by G. Poulett Scrope in his classic work upon volcanoes published in 1825. Upon his map he colors the Hawaiian Archipelago as volcanic: he says nothing of the observations of Ellis which were the only testimony from observations made on the island before that date; but remarks that navigators in the Pacific Ocean had seen lava flowing down the sides of Mauna Loa. Whether he made reference to the two instances quoted cannot be proved. It is very probable that Mokuaweoweo showed less activity after 1780 and before 1832 than in the decades since.

MOKUAWEOWEO BETWEEN 1832 AND 1843.

Rev. Joseph Goodrich is authority for the statement that lava flowed from several vents about the summit on June 20, 1832.[17] Light was observed from Lahaina on Maui, a hundred miles to the northwest.

Lava was seen coming out of the sides of the mountain in different places. Discharges of red hot lava were seen on every side of the mountain. This would seem to indicate that these flows were like all the later ones, not from the summit, but from some weak spot lower down. The reflection of fire upon the clouds at the first was probably regarded as evidence of a flow from the summit. Earthquakes were noted on Hawaii during the summer and quite an important display of activity was manifested at Kilauea, probably a few months earlier (Jan. 12).

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[17] A. J. Science, Vol XXV.

The impression prevails that these eruptions from Mokuaweoweo and Kilauea were simultaneous; and to reach this conclusion we must believe that the writing *Jan.* was a printer's error for June, in the account of Kilauea.

The records are meagre with respect to the location of this flow. The Government map shows a small area upon the south side of the caldera, and close to it, with the label of 1832. I have questioned everybody as to the authority for this representation, and no one connected with the Survey can give the information. Our doubt respecting this reference comes from the unusual position immediately adjacent to Mokuaweoweo. None of the eruptions on record later are so situated; they are lower down. Mr. Green refers its altitude to 13,000 feet in a table, but makes no remark concerning it in his text. The light was seen at Lahaina by Mr. Goodrich. That might have been the illumination always seen at the beginning of every flow. If the discharge was upon the south side it would not be very conspicuous from Maui. Mr. E. D. Baldwin suggests that there is a flow of recent lava, judging from its appearance, just inside of the great prehistoric Keamuku flow, arising near the beginning of the 1852 stream, which would have been visible from Lahaina, and might possibly have been erupted at this time. Keamoku is also well situated to answer the conditions even better, should the flow have been sufficiently recent.

In 1834 the summit was visited by Dr. David Douglas, an exploring naturalist. Some of his statements have been discredited because of apparent exaggeration of the terrific activity of Mokuaweoweo. He used instruments for the determination of altitudes and areas. He represented that there were great chasms in the pit that he could not fathom, even with a good glass when the air was clear. Upon the east side he used a line and plummet, and obtained the figure of 1,270 feet for the height of the precipice. The southern part of the crater presented an old looking lava. He heard hissing sounds apparently connected with internal fire. The greatest portion of this huge dome was said to be a gigantic mass of slag, scoriae and ashes.

Dr. Douglas lost his life shortly after his return from Mokuaweoweo. As his remains were found in a pit where wild cattle were entrapped it was supposed at first that he had accidentally fallen into it and was gored to death; but recently it has been ascertained that he had been thrown into this pit Jan. 27, 1834, by a bullock hunter named Ned Gurney, an Australian convict. This statement comes from Bolabola, an Hawaiian who was ten years old at the time of the homicide. He and his parents were

intimidated by Gurney, so that fifty or sixty years passed before he was willing to testify to the nature of the transaction.

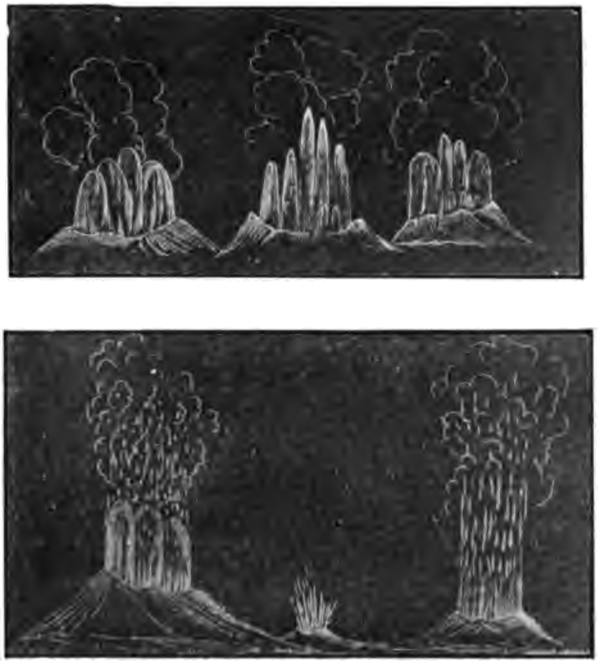
S. E. Bishop says of this locality: In March, 1836, I looked into the pit where David Douglas perished. It was close to the inland trail from Waimea to Laupahoehoe, on the N. N. E. side of Mauna Kea, ten or fifteen miles northwest of Laupahoehoe and in the woods.

THE WILKES PARTY UPON MAUNA LOA.

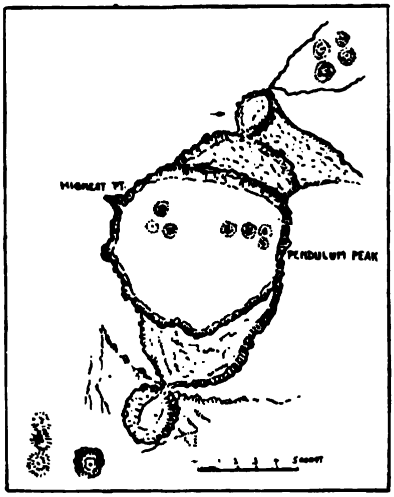
The most elaborate attempt to take observations upon Mauna Loa was that of the United States exploring expedition in 1840-41. Captain Wilkes, the officer in command of the expedition, wished to apply the best apparatus of his time for the determination of geodetic positions and altitudes besides observing the volcanic phenomena and mapping the country. His ship anchored at Hilo. The party started December 14, 1840, and the last of them returned to Hilo, Jan. 23, 1841, making an absence of forty-two days. Twenty-eight days were spent upon Mauna Loa; six days were required to make the ascent and two for the descent to Kilauea. At the beginning the company was to be compared to a caravan. It consisted of two hundred bearers of burdens, forty hogs, a bullock and bullock hunter, fifty bearers of poi, twenty-five with calabashes of different shapes and sizes, from six inches to two feet in diameter. Some of the bearers carried the scientific apparatus, others parts of the house to be erected on the summit, tents, knapsacks and culinary utensils. There were lame horses and as many hangers on as there were laborers. The natives moved under the direction of Dr. G. P. Judd, without whose help the expedition would have been a failure. After the start thirty more natives were added to the company so as to equalize the burdens. After passing Kilauea the number of the party was somewhat reduced, but there were still three hundred persons in all to be provided with food and water. Sickness and accidents led to the establishment of the Recruiting Station or hospital at the altitude of 9,745 feet. All the party experienced more or less of mountain sickness. The final encampment was on the edge of the pit of Mokuaweoweo, and the party suffered much from the inclement weather. There were a dozen separate tents and houses, all surrounded by a high stone wall. These are shown in Plate 16A. Fifty men were detailed from the vessel to complete the undertaking. The serviceable natives returned down the mountain after the necessary articles had been brought

PLATE 16.

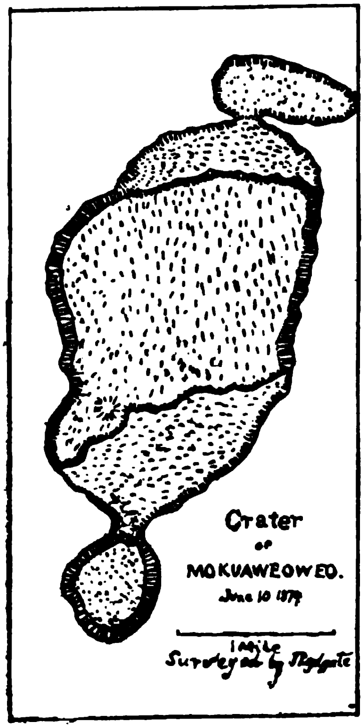
A. Camp Wilkes, Summit of Mauna Loa.



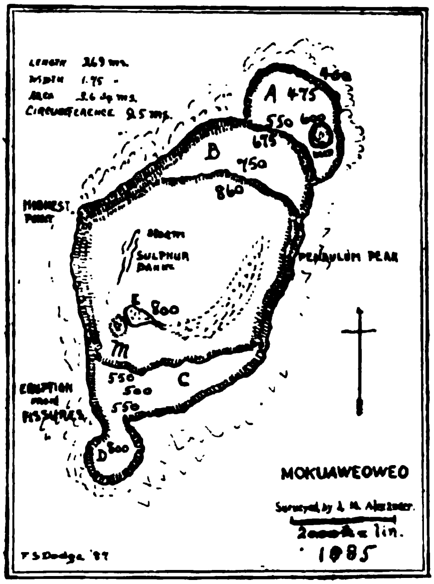
B. Lava Fountains, Flow of 1859.



A. Plan of Mokuaweoweo, 1841.



B. Plan of Mokuaweoweo, 1873.



C. Plan of Mokuaweoweo, 1885.

up, and came back after the termination of the observations in order to transport this valuable apparatus back to the ship.

The following facts were stated about the mountain: Its whole area was of lava, chiefly of very ancient date, rough and seemingly indestructible, made up of streams that had flowed from the central vents for many ages. Both pahoehoe and clinkers (aa) abounded. Wilkes concluded that the clinkers were formed in the great pit where they were broken and afterwards ejected with the more fluid material. Their progress would have continued till the increased bulk and attendant friction arrested the stream. Pahoehoe seemed to have flowed from the clinker masses that had been stranded. The crater was likened to an immense caldron, boiling over the rim, and discharging the molten mass and scoria which had floated on its top.

From the plan of Mokuaweoweo as given by Wilkes, Plate 17A, the following points may be made. The central part is the deepest, seven hundred and eighty-four feet by the west bank and four hundred and seventy feet by the east. This part is 9,000 feet in diameter nearly circular. The bottom is flat, with ridges from ten to fifty feet high, alternating with deep chasms and pahoehoe. Skirting this pit on both the north and south sides are lunate platforms apparently two-thirds as high as the summit rim, both together having an area perhaps half that of the main depression, and their outer rims coincide with the outline of the whole caldera. Just outside of both are smaller pits, the northern one two hundred feet and the southern nearly three hundred feet in diameter. The last has the name of Pohaku o Hanalei from Wilkes, showing seventy layers of basalt in the walls, and a cooled stream of lava that came from the larger crater. A smaller pit-crater is mapped to the south. There are many deep fissures about these pits and the lava has a very fresh appearance, being suggestive of obsidian. From the Pohaku o Hanalei a great steam crack points southerly. The highest point in the rim is opposite the encampment, with the altitude of 13,780 feet, three hundred and forty feet higher than at the station, which had the name of Pendulum Peak. Mauna Kea proved to be one hundred and ninety-three feet higher than Mauna Loa. Water boiled at 187° Fah. at Pendulum Peak. For some reason the main axis of Mokuaweoweo was placed at N. and S. instead of N. 26° E. It differed from Kilauea in the absence of a black ledge and a boiling lake and the evidences of heat were scant. There was one cinder cone at least upon the floor. Sodium and calcium sulphates, magnesium and calcium carbonates, ammonium sulphates and sulphurous gases were met with in the pit.

The clinkers were compared to the scoriae from a foundry, in size from one to ten feet square, armed on all sides with sharp points. The fragments are loose with a considerable quantity of the vitreous lava mixed with them.

As to origin, both the smooth and rough varieties are conceived to have been ejected in a fluid state from the terminal (summit) crater. The "clinkers" are seldom found in heaps, but lie extended in beds for miles in length, sometimes a mile wide, and occasionally raised from ten to twenty feet above the general slope of the mountain. The "clinkers" were formed in the crater itself, broken up by contending forces, ejected with the more fluid lava, which carried it down the mountain slope until arrested by the accumulating weight or by the excessive friction. They were streams of lava: and this opinion was fortified by the observation that pahoehoe came out from underneath the masses of clinkers wherever they had stopped. The crater was an immense caldron boiling over the rim. No facts are presented in favor of this view, and the idea was evidently borrowed from the conception of what a volcano should be. There had been no signal eruption previous to 1840 when the characteristic stream flows of this mountain had been developed.

ERUPTION OF 1843.

According to Dr. Andrews, smoke was first seen from Hilo above the summit, January 9th. The next night a brilliant light appeared above the summit like a beacon fire. By day great volumes of smoke were poured forth, and for a week there was a fire by night. The summit fire was then transferred to a point near the ridge leading towards Hilo about 11,000 feet high. The lava flowed from two craters toward Mauna Kea, according to Mr. Coan, who ascended to the source of the flow. It was supposed at first that the eruption was an overflow from the summit: this was before the behavior of the flows from very high up the mountain was understood. The lava spread out broadly from about the altitude of 11,000 feet to the base of the dome, and then rolled in a northwesterly direction towards Kawaihae more than sixteen miles. The lowest point of the stream in the saddle between Mauna Loa and Mauna Kea was near Kalaieha or the Humuula sheep station. Though so stated by Mr. Coan, the map does not indicate that a branch of the stream was directed toward Hilo. The greatest width of the stream was four and a half miles. The beginning of the outflow was less than a mile and a half from Pohaku Hanalei. It trespassed slightly

upon the Keamoku flow, which started from Kokoolau at an unknown period and moved twenty miles to the Trig. station Keamoku, from 7,800 to 3,300 feet altitude. After the refrigeration of the surface of the lava, the melted material continued to flow under cover for more than six weeks. The angle of descent for the whole distance is six degrees, but occasionally there were steep pitches of twenty-five degrees. Large stones thrown upon the surface did not sink but were rapidly transported downwards and lost to sight. Mounds, ridges and cones were thrown up, from which steam, gases and hot stones were thrown. On March 6th snow was found upon the summit. During this eruption there was no sign of sympathy with it at Kilauea.

From a native newspaper, *Ka Hae Hawaii* (The Hawaiian Banner), Rev. W. D. Westervelt has made the following translation of an account of the eruption of 1843, in the *Paradise of the Pacific,* November, 1908.

The eruption of January 10, 1843, was described by Mr. Coan. In the morning while it was still entirely dark a small flame of Pele fire was seen on the summit of Mauna Loa, on the northeastern shoulder of the mountain. Soon afterward the fire opened another door and the lava rushed down the side directly opposite Mauna Kea. Two branches were pouring forth lava, filling the place between the two mountains, covering it with fire like the spreading out of an ocean. One branch went toward the foothills of Hualalai and the other toward Mauna Kea until the flow came to the foot of the mountain, when it divided, one part going toward Waimea and one toward Hilo. Four weeks this eruption continued without cessation. The fires could not come to the sea coast, but filled up the low places of the mountain and spread out all over the different plains. Then it was imprisoned.

Brilliant fires were noted at the summit in May, 1849, after the unusual activity in Kilauea. These lasted for two or three weeks, but there was no evidence of accompanying earthquakes or discharge of lava.

MOKUAWEOWEO IN 1851.

There was a small flow on the west side of the summit commencing August 8, 1851. The smoke and fire were visible at Hilo. From Kona the light was gorgeous and glorious. Detonations were heard during the eruption, like the explosion of gases or rending of rocks. According to Professor Brigham, who visited the site in 1864, the starting point was 1,000 feet below the summit or two hundred feet below the floor of the caldera. The

stream was ten miles long and less than a mile in width. Most of the lava was pahoehoe, with some aa, and seemed to have cooled rapidly. The course was westward, following very closely an earlier prehistoric flow reaching down to Kealakeakua. The eruption continued but three or four days.

ERUPTION OF 1852.

The preceding eruption was really the opening scene of a fine exhibition six months later which started on the north side of the mountain, February 17th. On February 20th, the chief flow had shifted to another place about 10,000 feet above the sea level. The escaping lava rose at first in a lofty fountain, and then flowed easterly twenty miles.

I quote quite extensively from Mr. Coan; *Amer. Jour. Science,* 1852.

"At half past three on the morning of the 17th ultimo, a small beacon light was discovered on the summit of Mauna Loa. At first it appeared like a solitary star resting on the apex of the mountain. In a few moments its light increased and shone like a rising moon. Seamen keeping watch on deck in our port exclaimed: 'What is that? The moon is rising in the West!' In fifteen minutes the problem was solved. A flood of fire burst out of the mountain and soon began to flow in a brilliant current down its northern slope. It was from the same point, and it flowed in the same line as the great eruption which I visited in March, 1843. In a short time immense columns of burning lava shot up heavenward to the height of three or four hundred feet, flooding the summit of the mountain with light and gilding the firmament with its radiance. Streams of light came pouring down the mountain, flashing through our windows and lighting up our apartments so that we could see to read large print. When we first awoke, so dazzling was the glare on our windows that we supposed some building near us must be on fire; but as the light shone directly upon our couch and into our faces we soon perceived its cause. In two hours the molten stream had rolled, as we judged, about fifteen miles down the side of the mountain. This eruption was one of terrible activity and surpassing splendor, but it was short. In about twenty-four hours all traces of it seemed to be extinguished.

"At daybreak on the 20th of February, we were again startled by a rapid eruption bursting out laterally on the side of the mountain facing Hilo, and about midway from the base to the summit of the mountain. This lateral crater was equally active with the

one on the summit, and in a short time we perceived the molten river flowing from its orifice direct towards Hilo. The action became more and more fierce from hour to hour. Floods of lava poured out of the mountain's side, and the glowing river soon reached the woods at the base of the mountain, a distance of twenty miles.

"Clouds of smoke ascended and hung like a vast canopy over the mountain, or rolled off upon the wings of the wind. These clouds assumed various hues—murky, blue, white, purple or scarlet—as they were more or less illuminated from the fiery abyss below. Sometimes they resembled an inverted burning mountain with its apex pointing to the awful orifice over which it hung. Sometimes the glowing pillar would shoot up vertically for several degrees, and then describing a graceful curve, sweep off horizontally, like the tail of a comet, further than the eye could reach. The sable atmosphere of Hilo assumed a lurid appearance, and the sun's rays fell upon us with a yellow, sickly light. Clouds of smoke careered over the ocean, carrying with them ashes, cinders, charred leaves, etc., which fell in showers upon the decks of ships approaching our coast. The light was seen more than a hundred miles at sea, and at times the purple tinge was so widely diffused as to appear like the whole firmament on fire. Ashes and capillary vitrifactions called 'Pele's hair' fell thick in our streets and upon the roofs of our houses. And this state of things still continues, for even now (March 5th) while I write, the atmosphere is in the same yellow and dingy condition; every object looks pale, and sickly showers of vitreous filaments are falling around us, and our children are gathering them.

"As soon as the second eruption broke out I determined to visit it. Dr. Wetmore agreeing to accompany me, we procured four natives to carry our baggage, one of them, Kekai, acting as guide. On Monday, the 23d of February, we all set off and slept in the outskirts of the great forest which separates Hilo from the mountains. Our track was not the one I took in 1843, namely, the bed of a river; we attempted to penetrate the thicket at another point, our general course bearing southwest."

Without specifying matters relating to the party and circumstances, I quote the text farther on:

"At half past three P. M. I reached the awful crater and stood alone in the light of its fires. It was a moment of unutterable interest. I seemed to be standing in the presence and before the throne of the eternal God, and while all other voices were hushed His alone spoke. I was 10,000 feet above the sea, in a vast solitude untrodden by the foot of man or beast; amidst a silence un-

broken by any living voice, and surrounded by scenes of terrific desolation. Here I stood almost blinded by the insufferable brightness; almost deafened with the startling clangor; almost petrified with the awful scene. The heat was so intense that the crater could not be approached within forty or fifty yards on the windward side, and probably not within two miles on the leeward. The eruption, as before stated, commenced on the very summit of the mountain,[18] but it would seem that the lateral pressure of the embowelled lava was so great as to force itself out at a weaker point in the side of the mountain, at the same time cracking and rending the mountain all the way down from the summit to the place of ejection. The mountain seemed to be siphunculated; the fountain of fusion being elevated some two or three thousand feet above the lateral crater, and being pressed down an inclined subterranean tube, escaped through this valve with a force which threw its burning masses to the height of four or five hundred feet. The eruption first issued from a depression in the mountain, but a rim of scoriae two hundred feet in elevation had already been formed around the orifice in the form of a hollow truncated cone. This cone was about half a mile in circumference at its base, and the orifice at the top may be three hundred feet in diameter. I approached as near as I could bear the heat, and stood amidst the ashes, cinders, scoriae, slag and pumice, which were scattered wide and wildly around. From the horrid throat of this cone vast and continuous jets of red-hot and sometimes white-hot lava were being ejected with a noise that was almost deafening, and a force which threatened to rend the rocky ribs of the mountain and to shiver its adamantine pillars. At times the sound seemed subterranean, deep and infernal. First, a rumbling, a muttering, a hissing or deep premonitory surging; then followed an awful explosion, like the roar of broadsides in a naval battle, or the quick discharge of pack after pack of artillery on the field of carnage. Sometimes the sound resembled that of 10,000 furnaces in full blast. Again it was like the rattling of a regiment of musketry; sometimes it was like the roar of the ocean along a rock-bound shore; and sometimes like the booming of distant thunder. The detonations were heard along the shores of Hilo. The eruptions were not intermittent, but continuous. Volumes of the fusion were constantly ascending and descending like a *jet d'eau.* The force which expelled these igneous columns from the orifice shivered them into millions of fragments of unequal size, some of which would be rising, some

[18] Refers to the beacon light of the 17th instant.

falling, some shooting off laterally, others describing graceful curves; some moving in tangents, and some falling back in vertical lines into the mouth of the crater. Every particle shone with the brilliancy of Sirius, and all kinds of geometrical figures were being formed and broken up. No tongue, no pen, no pencil can portray the beauty, the grandeur, the terrible sublimity of the scene. To be appreciated it must be felt. * * * During the night the scene surpassed all power of description. Vast columns of lava at a white heat shot up continuously in the ever varying forms of pillars, pyramids, cones, towers, turrets, spires, minarets, etc., while the descending showers poured in one incessant cataract of fire upon the rim of the crater down its burning throat and over the surrounding area;—each falling avalanche containing matter enough to sink the proudest ship. A large fissure opening through the lower rim of the crater gave vent to the molten flood which constantly poured out of the orifice, and rolled down the mountain in a deep, broad river, at the rate probably of ten miles an hour. This fiery stream we could trace all the way down the mountain until it was hidden from the eye by its windings in the forest, a distance of some thirty miles. The stream shone with great brilliancy in the night, and a long horizontal drapery of light hung over its whole course. But the great furnace on the mountain was the all absorbing object."

May 6. "The great furnace on the mountain is still in terrible blast. No decrease of activity, but rather an increase."

In July Mr. Coan again visited the flow. The fires had ceased. A kind of pumice was very plentiful, beginning ten miles from the cone. It grew more and more abundant till the source of the flow was reached—where it covered everything to the depth of five to ten feet.

Messrs. H. Kinney and Fuller visited the source of this flow in March.[19]

Mr. Kinney described jets rising from four hundred to eight hundred feet and represented the existence of a deep unearthly roar, comparable to that of Niagara, heard a long distance away. The heat also created terrific whirlwinds. The two gentlemen agreed that the diameter of the crater from which the fountain rose was about 1,000 feet; the height of the crater from one hundred to one hundred and fifty feet; height of the fountain two hundred to seven hundred feet, rarely below three hundred;

[19] Amer. Jour. Science, 1852, XIV, p. 257.

and the diameter of the fountain from two hundred to three hundred feet. The jet sometimes became a Gothic spire of two hundred feet, then after subsiding stood at three hundred feet with points comparable to architectural ornaments. Rev. D. B. Lyman of Hilo confirmed these estimates. The lava streams sometimes seem to have been two hundred to three hundred feet thick.

Rev. E. P. Baker of Hilo visited the scene of this overflow in 1889 and found a single red cone in the midst of much pumice. There seemed to have been only one outlet. The lower part oi the stream consisted of aa changing to pahoehoe higher up.

THE ERUPTION OF 1852.

Described in verse by Titus Coan, and published in the *Friend*.

Hark! hark! while yet 'tis dark
There's a deep, rumbling sound,
As of spirits underground,
Rolling rocks for melting,
Gathering ore for smelting.

Hark! while night is still dark
In earth's hidden caves,
Theres' a noise as of waves
    Muttering, sputtering,
    Splashing dashing,
Like the sound of the surf,
Like hoof on the turf.
    A shake and a shiver,
    A quake and a quiver.

    Hush! Hush!
For a moment all is still
On yon dark and distant hill.
Nature stands all awed and silent,
While stern Pluto lifts his trident,
Seated on a sulphur throne.
To us mortals all unknown
In the distant realms of wonder
Vulcan forges bolts of thunder.

Hark! hark again!
Still a rumbling now and then;
Old Vulcan blows; the furnace glows;
Earth's ribs are rent; hot fumes find vent.
Fire! Fire! higher, still higher,
The glaring columns rise.
A burning flood like Hell's hot blood,
An angry cloud, with thunders loud,
Shoots upward to the skies.

And now on high, 'gainst flaming sky
Stand turrets, towers, minarets, spires,
All dazzling with devouring fires.
A pillar of light, which scatters old night;
Rising, sinking, standing, swaying,
A red, molten fountain,
On a dark, heaving mountain.

Look! Look!
A pyramid of glowing coals,
From whose direful vortex rolls
Curling smoke of every hue—
Crimson, purple, sable, blue—
Convolving clouds of varied dye,
Emblazoned on the fretted sky.

Sweeping like a comet's tail,
Blazing like a meteor's trail.
Like the track of fierce Mars,
On his burning wheeled cars,
Like the bright, gleaming sword
In the hand of the Lord!
Down, down the mountain's sides.

A fiery dragon glides
Old marble melts along his way,
His eyes turn midnight into day,
His flaming tail is waved on high,
And sweeps night's watchman from the sky.
Hush! hush!
There's a rush and a rattle
Like armies in battle!
Squadrons dashing; broad swords clashing,
Sables gleaming, red blood streaming.

There's a break and a roar,
Like the wave on the shore,
Like the crash of dread thunder
    Rending earth asunder
    Like the fiat of God,
    Shaking Earth with His nod
    Like the breath of His ire
    Setting Heaven on fire;
    Like the roaring on high
    When His chariots draw nigh;
    Like the trump's direful blast
    When Time' cycles are past.

Smoke, fire, sulphur, nitre,
Glaring brighter and still brighter.
Bang, bang, bang! clang, clang, clang!
    Harsh, heavy, shrill,
O'er mountain, dell and hill,
Heaven's high artillery rang.

Flaming meteors dance around;
Burning whirlwinds sweep the ground:
A fiery hail from clouds above
Is scattered wide o'er mountain wide.
    See! see!
Dread Typhœus' forge is sevenfold blast,
And lasting hills dissolving fast.
The glowing furnace fiercer glows;
The blood red river, hotter flows;
Rocks rend, roar, melt and disappear,
Mingling in wild and mad career.

Clouds gather, infold, gyrate, brighten,
Thicken, darken, thunder, lighten,
Sigh the winds, and howl and rave,
Driving hot cinders o'er wildwood and wave.
From morn till night, pale yellow light
Below; on high, shrouds earth and sky.
Dark forests blaze in the flame's red rays,
Then vanish from sight, like a specter of night.
    Upon the fiery tempest's breath,
    Desolation rolls on death.

Ah, Pele, dread Goddess of Fire,
Why flash thine eyes with kindling ire?
Why stir afresh thy everglowing coals,
While from thy throat this burning river rolls?
Why wreathe thy mythic head in smoke and flame?
And startle mortals with thy fearful name?
Why rend thy hoary locks and scatter thy silver hair?
Why sound thine awful trumpet forth
Upon the midnight air?

But, hush once more; the scene is o'er;
For twice ten days the fountain plays;
Then all is still; o'er dell and hill:
The whirlwind's sweep is lulled to sleep
Hell's burning breath is quenched in death,
From murky cloud the thunder loud
Has ceased to roar on mount and shore,
The awful blast has hurried past,
The fiery flood obeyed its God;
"Thus far," He said, "and here he stayed."

ERUPTION OF MARCH, 1852.

BY J. FULLER in the *Friend,* May, 1852.

On reaching the seat of activity, he writes thus:

"Imagine yourself, then, just ascended to the top of the above mentioned eminence. Before you at a distance of two miles, rises the new formed crater in the midst of fields of black, smoking lava, while from its centre there jets a column of red hot lava to an immense height, threatening instant annihilation to any presumptuous mortal who shall come within the reach of its scathing influence. The crater may be 1,000 feet in diameter and from one hundred to one hundred and fifty feet high. The column of liquid lava which is constantly sustained in the air, is from two hundred to five hundred feet high, and perhaps the highest jets may reach as high as seven hundred feet! There is a constant and rapid succession of jets one within another, the masses falling outside and cooling as they fall, form a sort of dark veil, through which the new jets darting up with every degree of force and every variety of form render this *grand fire fountain* one of the most magnificent objects that human imagination can conceive of."

The finer products, ashes and pumice, fall in constant showers

for some miles around the vent. Besides several craters formed from earlier eruptions there is a small one still steaming, which seems to have been the first outbreak. Below it are several fountains constantly pouring out an immense quantity of molten lava, which flows in a glowing stream down the mountain slope.

This flow came within seven miles of Hilo, says the Editor.

ERUPTION OF 1855.

This commenced August 11th and continued for sixteen months. The amount of lava ejected was the greatest of any of the flows seen by modern observers. The only witnesses of the scene on record were Titus Coan, S. E. Bishop and F. A. Weld. It started from a point 12,000 feet high and nearer the summit than the preceding flow. The first thing seen was a small point of light much like Sirius; it threw off coruscations of light and soon resembled a full orbed sun. As the stream continued to flow directly towards Hilo, the inhabitants grew more and more anxious and made frequent trips to determine its progress. Mr. Coan went up early in October. In three days he reached the place where it was three miles wide. Usually it was broader, sometimes reaching a width of eight miles.

"Early on Saturday the 6th," he says, "we were ascending our rugged pathway amidst steam, smoke and heat which almost blinded and scathed us. At ten we came to open orifices down which we looked into the fiery river which rushed furiously beneath our feet. We had seen in the night many lights like street lamps, glowing along the slope of the mountain at considerable distances from each other, while the stream made its way in a subterranean channel, traced only by these vents. From 10 A. M. and onward these fiery vents were frequent, some of them measuring ten, twenty, fifty or one hundred feet in diameter. In one place only, we saw the river uncovered for thirty rods and making down a declivity of from ten to twenty-five degrees. The scene was awful, the momentum incredible, the fusion perfect (a white heat), and the velocity forty miles an hour. The banks on each side of the stream were red-hot, jagged and overhanging, adorned with burning stalactites and festooned with immense quantities of filamentose or capillary glass, called Pele's hair. From this point to the summit crater all was inexpressibly interesting. Valve after valve opened as we went up, out of which issued fire, smoke and brimstone, and down which we looked as into the caverns of Pluto. The gases were so pungent that we had to use the greatest caution, approaching a stream or an orifice

on the windward side, and watching every change or gyration of the breeze. Sometimes whirlwinds would sweep along, loaded with deadly gases and threatening the unwary traveller. After a hot and weary struggle over smoking masses of jagged scoriae and slag, thrown in wild confusion into hills, cones and ridges, and spread out over vast fields, we came at one P. M. to the terminal or summit crater (not Mokuaweoweo).

"This we found to be a low elongated cone, or rather a series of cones, standing over a great fissure in the mountain. Mounting to the crest of the highest cone, we expected to look down into a great sea of raging lavas, but instead of this the throat of the crater, at the depth of one hundred feet, was clogged with scoriae, cinders and ashes through which the smoke and gases rushed up furiously from seams and holes. One orifice within this cone was about twenty feet in diameter, and was constantly sending up a dense column of blue and white smoke which rolled off in masses and spread over all that part of the mountain, darkening the sun and obscuring every object a few rods distant. * * * * The summit cone which we ascended was about one hundred feet high, five hundred long and three hundred broad at the base. Several other cones below us were of the same form and general character, presenting the appearance of smoking tumuli along the upper slope of the mountain. * * * The molten stream first appears some ten miles below the fountain crater."

The principal stream with all its windings was thought to be sixty miles long, lying between the flows of 1843 and 1852. From his various trips Mr. Coan had ascertained that a line of fissures extended from Mokuaweoweo for five miles down to the place of this outbreak, along which there were cones of scoriae and sand that had been thrown up at various times.

The progress of the front of the stream, owing to the obstructions of trees, depressions and irregularities, was very slow, not more than a mile per week. When there were obstructions the edge of the flow would become crusted, the lava behind would accumulate until the pressure became too great to be withstood, and then the liquid would burst through in a spurt and continue downwards till another set of obstructions caused an accumulation and another break allowed a discharge. Hence as one ascends any of the flows he seems to pass over a series of rough terraces.

Such a stream will also become widened by lateral discharge into a number of channels. After a free flowing for a while there may be much hardening of the crust and several days of in-

activity. "At length, immense areas of the solidified lava, four, five or six miles above the extremity, are again in motion; cones are uncapped, domes crack, hills and ridges of scoriae move, and great slabs of lava are raised vertically or tilted in every direction."

October 22, seventy-two days after the commencement of the eruption, the fountain still continued to flow. Mr. Coan made another trip—this time to the lower end of the stream. A river of water below had become discolored with the pyroligneous acid distilled from the burning trees and the water turned black. He attempted several times to cross the stream. "The hardened surface of the stream was swelling and heaving at innumerable points by the accumulating masses and the upraised pressure of the lava below; and valves were continually opening, out of which the molten flood gushed and flowed in little streams on every side of us. Not a square rod could be found on all this wide expanse, where the glowing fusion could not be seen under our feet through holes and cracks in the superincumbent stratum on which we were walking. The open pits and pools and streams we avoided by zigzag course; but as we advanced these became more numerous and intensely active, and the heat becoming unendurable we again beat a retreat after having proceeded some thirty rods upon the stream. It may seem strange to many that one should venture on such a fiery stream at all, but you will understand that the greater part of the surface of the stream was hardened to the depth of from six inches to two or three feet; that the incandescent stream flowed nearly under this crust like water under ice, but showing up through ten thousand fissures and breaking up in countless pools. On the hardened parts we could walk, though the heat was almost scorching, and the smoke and gases suffocating. We could even tread on a fresh stream of lava only one hour after it had poured from a boiling caldron, so soon does the lava harden in contact with air."

Both Mr. Coan and Professor Dana are on record as saying that there must have been fissures far down the mountain from which lava issued, as well as from the source 12,000 feet high. The latter, however, does not speak of them in his latest description of this flow, so that it may be inferred that he had ceased to entertain that view.

March 6, 1856, Mr. Coan writes: "The great fire-fountain is still in eruption and the terminus of the stream is only five miles from the shore. The lava moves slowly along on the surface of the ground, and at points where the quantity of lava is small, we dip it up with an iron spoon held in the hand. During the last

three weeks the stream has made no progress towards Hilo, and we begin to hope that the supply at the summit-fountain has diminished. There is, however, still much smoke at the terminal crater." This hope became fact. The stream stopped at a point about five miles above Hilo.

Mr. Coan visited this flow eight times during its history. On the 22nd of October, 1856, he writes more fully about the supposed fissures: "A fracture or fractures occurred near the summit of the mountain which extends in an irregular line from the terminal point, say five miles down the northeast slope of the mountain. From this serrated and yawning fissure, from two to thirty yards wide, the molten flood rushed out and spread laterally for four or five miles, filling the ravines, flowing over the plains, and covering all those high regions, from ten to one or two hundred feet deep. Along this extended fissure, elongated cones were formed at the points of the greatest activity. These cones appear as if split through their larger diameter, the inner sides being perpendicular or overhanging, jagged and hung with stalactites, draped with filamentous vitrifications, and encrusted with sulphur, sulphate of lime and other salts.

"The outsides of these cones are inclined planes, on an angle of forty or sixty degrees, and composed of pumice, cinder, volcanic sand, tufa, etc. You will not, however, understand that these semi-cones were once entire and that they have been *rent*: they are simply masses of ridges of cinder and dross deposited on each side of the fractures where the action is greatest. *It is all a new deposit.* After you leave the region of open fissures, near the summit of the mountain, all below *appears to be a flow on the surface.*" [20]

ERUPTION OF 1855.

Statement by S. E. Bishop, dated January 22, 1856.

From the *Friend,* March, 1856.

We found a considerable ascent between the shore and the present terminus of the lava, which is about seven miles from the town, towards which it is directly advancing with unabated activity. There still intervenes about three miles of dense forest and jungle between it and the open ground. It has now been flowing about twenty-three weeks, all but the first two or three

[20] Mr. Coan's numerous letters appeared chiefly in the *American Journal of Science.*

of which have been occupied in fighting or gnawing its way with sluggish but resistless force through ten or twelve miles of forest. The whole stream is some sixty miles long. Its rate of advance has been for a long time quite steady at about one mile in two weeks. These data may enable you to calculate how long it must continue to run to complete its victory over its most formidable obstacle, the forest, which has so far been the means of preserving the harbor of Hilo from its terrific invasion. It was about dark, when having ascended for one hundred rods the bed of the branch of the Wailuku River, we mounted a *pali* between two nearly dry cascades and found ourselves in the presence of the blazing woods and jungle. Passing up a few yards, we suddenly stumbled on the flowing lava, in a narrow dull sluggish stream, filling a side channel of the brook. It being in small quantity, yet in a state of fusion, gave us an admirable opportunity of obtaining such specimens as we could conveniently take away. This lava appeared to be about a hundred yards in advance of a large body of the same about three hundred yards wide which was vigorously burning its way down toward us through the woods. We finally laid down in a place that seemed secure, on the brow of a dry cascade; but at three A. M. a body of the enemy came down in strong force and routed us out to watch its movement. Unobstructed in the smooth channel it rolled on about one hundred feet an hour, its front a glaring red, cooling as it flowed. At four a bright tongue darted forward and rolled with dull plash over the precipice. We sprang down to witness the marvelous sight. A brilliant cascade of intensely bright lava was pouring down a height of twenty-five feet, first in a broken, and at last in a continuous torrent, striking on a ledge and sliding off into the deep pool below, which hissed and roared in agonizing resentment at the horrible intrusion upon its placid slumber. The sheet of fire was about six feet wide, narrowing beautifully till it struck the rock, where it gradually heaped a mound of half solidified lava, which would now and then crash down into the water, which would then splutter and fly in all directions, while a glorious column of white vapor rose far aloft. We felt that we had a spectacle provided for us, and until day broke we stood devouring it with our eyes. No words can describe the exquisite and entrancing beauty of the whole scene, of which the hideous crawling monster we had seen above thus suddenly transfigured and leaping in glory now became the center and the gem. Imagine a scene of most dim and delicate beauty, such as you may have seen or thought of, a silver cascade with its flashing foam and dark romantic amphitheater of cliff and forest all thrown into dim but

rich relief by a full moon in a cloudless sky, then change your pale silver flood into one of intense burning gold, rolling down still and bright as the heart of a furnace, and you can imagine what a gem we gazed on and in what a setting. Nor did the grand white column of steam detract from the beauty of the sight. But day broke, the moon paled; the bright flood was again encased in its black and hideous mail, a huge mound of smoking scoriae was filling the basin, and the boiling water was flowing by our feet. So we returned up the other side of the stream to observe by daylight the great river of lava above. Making our way to its edge in various places, we were enabled to see what a vast river of it, now congealed in black misshapen billows of coke-like stone, had forced its way from the S. W. past the point where we stood, towards the Wailuku River, but that it had paused in that direction and had broken out on the side where we stood, pushing forward long tongues of fire into the timber as an advance and following these up in mass, burning and covering what they had spared. In one case we walked one hundred yards through the woods upon a slender thread of cooled lava, say fifteen feet wide, across which lay trees and bushes whose roots it had burned away. But everywhere the following fusion forbade our passage on to the main stream. This we judged to be more than a mile wide. Its depth is irregular. In the center it appeared to be heaped up thirty to fifty feet. We estimated its breadth by the appearance of the trees beyond. But for this test to correct deceptive appearance, I should have called it not above one hundred yards wide. The advancing phalanx of fire was about to reach *en masse* the wider and deeper channel of the stream below the fall, where it was evident so much of it as the capacity of the channel would admit, would pass forward with rapidity, and might run on even miles in advance of the rest. But even should this small portion soon pass down the Wailuku and reach the sea it could do no fatal injury. Should the main body take the same course as appearances indicate it would, the town and harbor would be totally destroyed. It is, however, the opinion of some who are familiar with the ground that the general direction of the lava after leaving the woods would be to the southward of the town, across the Waiakea River, and into the bay near the present projecting reef which forms the harbor. It is of little use to speculate upon the result. This great eruption is an appalling thing. The hand of God governs it. He can turn its course or stay it altogether. But our fears are not allayed when we look at Mauna Loa and see those two vast columns of smoke which it is still pouring forth. Some here have

in their fears that faith in the Hearer of Prayer which God's word justifies, and are supplicating the Divine interposition to avert the threatened calamity.

Mr. F. A. Weld, an Englishman, visited the 1855 flow Nov. 16th, coming up from Kilauea. He passed the source of the '52 eruption, 10,000 feet above the sea, and reached the lava stream about three miles below the uppermost crater. The stream was about two miles wide, presenting every variety of form and distortion, sometimes with a smooth surface, broken by cracks and fissures, elsewhere twisted like strands of coiled rope or rolled out into huge waves and serpentine convolutions. Smoke and steam rose from it in many places, and the rock was hot, not far distant from the liquid fire. He had a fine view of the fiery flood below where the surface had fallen down. The huge arch and roof glowed red-hot and the glare was perfectly scorching. The lava at almost white heat moved from three to four miles per hour. Stones thrown upon the stream were carried along. The "lower crater" consisted of dark fantastically shaped rocks, volumes of smoke, heaps of stones, surrounded by an ocean of partially cooled lava. The discharge was entirely subterranean. He attempted to look down one of the chimneys but could see only a long, broad fissure filled with smoke in the brief period when he could observe without suffocation. The "upper crater" was composed of an infinity of steam and smoke vents at the foot and on the sides of two large mounds or hills of small loose stones, probably lapilli. Volumes of red smoke and partially ignited gases issued from the earth which would appear as actual flame by night. The altitude was estimated to be 12,000 feet and six or eight miles below the summit of Mauna Loa, 1,500 feet higher. The stream of lava below was advancing about a mile per week.—From *Quarterly Journal Geol. Soc.*, London, Vol. 13.

THE ERUPTION OF 1859.

This started at an elevation of 10,500 feet on the north side of Mauna Loa and was observed by President Beckwith and Professors R. C. Haskell and W. D. Alexander of Oahu College, Rev. L. Lyons of Waimea, Rev. Titus Coan, and by W. Lowthian Green. Most of these gentlemen have published their views of the phenomena from which it is possible to compile a satisfactory sketch. It is the only flow from high up the mountain which succeeded in reaching the ocean. There was an opening four miles higher up than the principal scene of display, for there is a narrow stream of lava following a crevice to the uppermost place of

discharge. Mr. Vaudrey, an English traveler, happened to be upon Mauna Loa when this eruption broke out, and with his guides he hastened to this spot. There was a simple fountain of white-hot molten stone rising hundreds of feet into the air, and falling with a continual dull roar.

Rev. Mr. Lyons states that on Jan. 23d smoke was seen from Waimea gathering upon Mauna Loa. In the evening lava spouted out at the upper opening and soon another jet appeared at the lower crater. No earthquakes were noted in connection with this outbreak; but between Oahu and Molokai parboiled fish were seen for several days after the 21st. At Honolulu the atmosphere was so thick and hazy as to cause excitement before the news of the outbreak came. The Oahu College party started for the scene Feb. 1st, reaching Kealakekua on the 3d of February. The stream had on Jan. 31st reached the sea at Wainanalii, a dozen miles south of Kawaihae, a distance of thirty-three miles, in eight days. From a distance of twenty-five miles liquid lava could be seen issuing from a crater one hundred and fifty feet high and two hundred feet in diameter, spouting up to the height of three to four hundred feet. It was somewhat inconstant, at one time being very high and narrow at the top, and then quite broad with a less altitude. Two sketches show the conditions as seen first Feb. 6th and 7th, and then on the 10th. Plate 16B. The two craters on the last date were about eighty rods apart, sending up gas and steam with appearances of flame. The noise was like that of an ascending rocket, and occasionally like discharges of artillery. These two craters were half a mile above the place where the lava stream commenced, continuing in a winding river of light for several miles and then dividing into a network of branches.

Alexander says: "The two principal cones are about a quarter of a mile apart, the upper one bearing S. E. from the other. They are about one hundred and fifty feet high and are composed entirely of pumice and small fragments of lava which were thrown out in a liquid state. The upper cone was a closed crater, enclosing two red-hot vent holes or furnaces, several feet in diameter, from which it was emitting steam and sulphurous gas, and now and then showers of light pumice. The suffocating gases rendered it impossible to approach it except on the windward side. The lower crater from which the great jet had been playing two days before was somewhat larger, and a great gap was left open on the lower side through which a torrent of lava had flowed down the slope. We found a third crater above the two we have mentioned, which was still smoking; and in fact we could trace

a line of fresh lava and scoria cones two or three miles further up the mountain."

Mr. W. L. Green visited the source of this eruption about the same time. When camped near the stream he heard explosions all night long like heavy cannon; which he ascribed to an explosion under a stream of lava of highly heated compressed air. Fifteen miles below the source he estimated the height of the pillar of cloud by day and of fire by night at 10,000 feet and the width of five hundred feet. The fountain seemed to him to have broken out at the intersection of two fissures, one leading towards the top of the mountain and the other at right angles to it.

A year later Mr. Green visited the source of this flow and found a small cone, which was the mouth of a chimney, eighteen to twenty-eight feet wide and of unknown great depth. The stream below was compared to a hollow pie—the contents had disappeared leaving only a broken down crust.

On the morning of Feb. 10th the Oahu party visited the beginning of the flow for the last time. The lava rushed out of the subterranean passage with great velocity, at a white heat and as thin as water. Masses of lava were thrown up from ten to fifty feet into the air which cooled in falling. Three hours later the pool had become a fountain playing to the height of thirty feet. Plate 16B. Pieces of the lava ascended as much as one hundred and eighty feet and cooled as they fell. Gases were escaping at two other points. The crater was ten feet high. This jet had been discharging for fifteen days.

Concerning the stream below, Alexander writes: "It was fortunately a clear day on the mountain, and a strong wind was blowing from the southwest, so that we traveled for three or four hours along the very brink of the stream without inconvenience. It had worn for itself a deep, well defined channel, so that there was no danger of any sudden change in its course. The canal in which it ran varied from twenty to fifty feet in width and was ten to fifteen feet deep. But the stream was in reality much wider than this, for the banks on either side were undermined to a considerable distance. Often we met with openings in the crust, through which we could see the rushing torrent a few feet, or even inches, below our feet. * * * We saw actual waves and actual spray of liquid lava. As its surges rolled back from the enclosing walls of rock, they curled over and broke like combers on the reef. Its forms, however, were bolder and more picturesque than those of running water, on account of its being a heavier and more tenacious fluid. There was besides an endless variety in its forms. Now passed a cascade, then a whirl-

pool, then a smooth majestic river, then a series of rapids, tossing their waves like a stormy sea; now rolling into lurid caverns, the roofs of which were hung with red-hot stalactites, and then under arches which it had thrown over itself in sportive triumph. The safety with which it could be approached was a matter of astonishment to us all. * * *

"As the descent became more gradual (eight or ten miles down) the torrent changed its color, first to rose color, then to a dark blood red; its surface began to gather a grayish scum, and large drifting masses became frequent. It now began to separate with numerous branches, and it became more unsafe to follow the central stream, as changes were constantly taking place, and our retreat was liable to be cut off at any moment. * * *

"We had been particularly anxious to see how clinkers are formed, and our curiosity was now gratified. The difference between pahoehoe, or smooth lava, and aa, or clinkers, seems to be due more to a difference in their mode of cooling than to any other cause. The streams which form the pahoehoe are comparatively shallow, in a state of complete fusion, and cool suddenly in a mass. The aa streams, on the other hand, are deep, sometimes moving along in a mass twenty feet high, with solid walls; they are less fluid, being full of solid points, or centers of cooling, as they may be called, and advance very slowly. That is, in cooling, the aa stream grains like sugar. At a distance it looks like an immense mass of half red-hot cinders and slag from a foundry, rolling along over and over itself, impelled by an irresistible power from behind and beneath. That power is the liquid stream, almost concealed by the pile of cinders which have been formed from itself in cooling."

Under date of June 22d, Professor Haskell writes, after a visit to the source of the '59 flow, that the stream was much smaller than in February; it is entirely subterranean for twenty-five or thirty miles, though a few holes exist where the lava can be seen. He climbed to Mokuaweoweo where no perceptible action was noted.

Mr. W. L. Green observed the entrance of the lava into the sea, both in January and several months later: "The red hot lava was quietly tumbling into the sea over a low ledge, perhaps six or eight feet high, and five hundred to six hundred feet long. The lava did not seem to be quite so liquid, or of such a bright color as it did when it ran out of openings in the side walls of the aa stream upon the mountain some months before. It ran more like porridge in great flattened spheroids, which were sometimes partially united together, and sometimes al-

most separate. The cooling was to be expected after its long journey down the mountain. There was no steam to be seen escaping from the lava, and it was not until after each spheroidal mass had disappeared for a second or two under water that puffs of steam came to the surface. The general effect, however, was an apparent steady rise of steam along the whole line. It was a cataract of molten stone."

Mr, Green remarked that this tendency to form spheroids in the molten state might have some connection with the origin of basaltic columns, as well as to weathered spheroidal masses seen in ancient lava streams, developed through decomposition and exhibiting concentric coats. He allows that there was nothing like compression: the great flattened spheroids rolled quietly over into the sea, causing a slight commotion in the water. The boat was pulled very near the boiling mass, and was set rapidly outward, because of the rise of water from below. The origin of the concentric structure is, however, quite likely to be explained by the production of these spheroids.

In 1864 Professor Brigham walked over more than eight miles of the upper part of the 1859 flow in an ascent of Mauna Loa, The surface was black, shining and quite brittle. In some places the lava had flowed up hill. Bubbles of great size were common, some of them broken in. Immense beds of aa with nearly vertical sides and extremely rough fragments crossed the flow in various directions, being always level on the top.

Mokuaweoweo varied scarcely from the conditions described by Wilkes. It was visited August 5th, and is alluded to later.

According to the record book, Messrs. J. L. Wisley, Charles Hall and M. Worman ascended to Mokuaweoweo in 1865. They went up on the north side past the source of the 1859 flow. The summit pit was said to be shaped like the figure 8. They descended to the bottom, finding two steam holes upon the west side. There was a line of openings or gashes up the mountain along the line of the 1859 flow, as well as pumice and sand at the point of outburst.

In 1865 light was seen at the summit of Mauna Loa, December 30th, and continued for four months, with variations in its intensity. No one ascended to the summit and there is no record of any outflow of lava anyhere upon the side of the mountain.

THE GREAT ERUPTION OF 1868.

This eruption had two peculiarities: 1, it was preceded by numerous and violent earthquakes; 2, the place of principal emer-

gence of the lava was low down the mountain, 10,000 feet below the summit. The flows previously described came from small orifices 10-12,000 feet above the sea, and it took the lava a long time to discharge. The one low down discharged in three or four days out of a long rent in the rock as much material as came from the higher openings for many months. The nature of the eruption was not understood at first, because it was so different from what had been previously observed from either Mokuaweoweo or Kilauea; save that it is now seen to have been like the discharge from Kilauea in 1840 near Nanawili. The chief observers were Messrs. T. Coan, H. M. Whitney, Dr. William Hillebrand, F. S. Lyman and other residents of the disturbed district.

On March 27, Friday, there were slight earthquake shocks in Kau and Kona. The following day they extended easterly to Hilo and northwesterly through Kona. On the 27th, fire and smoke were observed at the summit from Kawaiahae and Kealakekua, and from Hilo the day following. From Kau the report came that the first outbreak appeared on the southwest side of the summit, followed later by others on the same side; and soon there were four streams pouring down the mountain. By the 30th, the line of smoke advanced fifteen miles towards the south cape. No light was seen at the summit from Hilo after the 28th.

The earthquakes now began to be noticeable. Rev. C. G. Williamson in South Kona recorded seventy-six shocks between April first and tenth. In Kau there were certainly 300 at the same time; and the current statement is that the total number arose to 2,000. The culminating shock was at 3:40 P. M. April 2d. Walls were universally thrown down, houses moved or overturned. I saw one house (in 1883) still showing the amount of the throw to have been eight inches. The focus of the shock was thought to be at Keaiwa and is thus described by F. S. Lyman: "First the earth swayed to and fro north and south; then east and west, round and round; then up and down and in every imaginable direction for several minutes; everything crashing around us; the trees thrashing about as if torn by a rushing mighty wind. It was impossible to stand; we had to sit on the ground, bracing with hands and feet to keep from rolling over." At this moment there occurred the "mudflow", a slide where earth, trees houses, cattle, horses, goats and men were swallowed up and rocks thrown high into the air. At Waiohinu, ten miles to the S.W., a stone church was leveled to the ground and most of the other buildings were destroyed. Near this point there was a lateral shift of about

eighteen feet, extending along a fault line. The ground moved just about the width of the road makai.

The shocks were felt at a distance of three hundred miles to the N. W., or to Kauai, and on all the intervening islands. Three kinds were noticed: (1) the undulating, with a motion from N. W. to S. E.; (2) a sudden, short, sharp jerking shock occupying barely two seconds; (3) a thumping, like a cannon ball striking the floor beneath you and then rolling away. Rattling noises accompanied all three of these shocks. There was a motion to the N. E. at Hilo, well shown in upright cases in Mr. Coan's study. Books were thrown down from cases facing the southwest; while cases filled with minerals and facing to the northwest were undisturbed.

Concerning the "mudflow" Mr. Coan writes that it was a true land slide. "I went entirely around it, and crossed it at its head and center, measuring its length and breadth, which I found were severally three miles long and a half mile wide. The breadth at the head is about mile, and the ground on the side hill, where the cleavage took place, is now a bold precipice 60 feet high. Below this line of fracture the superstrata of the earth, consisting of soil, rocks, lavas, boulders, trees, roots, ferns and all tropical jungle, and water, slid or rolled down an incline of some twenty degrees, until the immense masses came to the brow of a precipice near a thousand feet high, and here all plunged down an incline of 40° to 70° to the cultivated and inhabited plains below. The momentum acquired by this terrific slide was so great that the mass was forced over the plain, and even up an angle of one and a half degrees, at the rate of more than a mile a minute. In its course it swept along enormous trees and rocks from the size of a pebble to those weighing many tons. Immense blocks of lava were uncovered by the slide. The depth of the deposit on the grass plains may average six feet; in depressions at the foot of the precipice it may be thirty or even forty feet."

The earthquake wave and its effects are thus described by Mr. Fornander: "At Punaluu (p. 297 of Green) at the moment of the shock, it seemed as if an immense quantity of lava had been discharged into the sea some distance from the shore, for almost immediately a terrible commotion arose, the water boiling and tossing furiously. Shortly afterwards, a tremendous wave was sweeping up on the shore, and when it receded, there was nothing left of Punaluu! Every house, the big stone church, even the cocoanut trees — all but two — were washed away. The number of lives lost is not yet ascertained. All who were out fishing at the time perished, and many or

those ashore. A big chasm opened, running from the sea up into the mountain, down which it is said lava, mud, trees, ferns and rocks were rushing out into the sea. The same wave that washed away Punaluu, also destroyed the villages of Ninole, Kawaa, and Honuapo. Not a house remains to mark the site of these places, except at Honuapo, where a small 'hale halawai' on the brow of the hill, above the village, stood on Friday last. The larger cocoanut grove at Honuapo was washed away, as well as that at Punaluu. A part of the big pali at Honuapo, on the road to Waiohinu, had tumbled into the sea, and people coming from thence are now obliged to take the mountain road through Hilea-uka."

H. M. Whitney says this wave rolled in over the tops of the cocoanut trees at Punaluu, probably sixty feet high, driving floating rubbish inland about a quarter of a mile, and bringing back everything moveable. The same wave washed in many large boulders at Pohoiki.

Professor Brigham summed up the losses as follows: Number of houses destroyed by land slide, ten; by the sea wave, one hundred and eight; deaths by the land slide, thirty-one; by sea wave, forty-six. Number of houses destroyed by earthquake, forty-six; by lava stream thirty-seven. Total houses destroyed, two hundred and one;; total deaths, seventy-seven.

The first stage in the eruptions about Kahuku occurred in the night of April 6th. There was a shower of ashes and pumice, covering the country ten or fifteen miles upon each side. These covered the ground for ten inches generally, but sometimes fifteen. Pieces of the pumice two or three inches wide floated forty-five miles up the Kona coast. On the morning of April 7th a lava stream originated some ten miles up the mountain, and was crossed by Mr. H. M. Whitney on the north side of the later eruption. He speaks of it as pahoehoe in a valley five hundred feet wide. It had ceased flowing in three days' time so that people could walk over it.

In the afternoon of April 7th, the principal eruption commenced, as a discharge from a crevice about three miles long and above the Kahuku Ranch. The inmates of Captain Brown's house saw the fiery stream making apparently for the house and they were not slow in vacating the premises, going towards Waiohinu. Mr, H. M. Whitney was able to witness a part of this flow from a small hill westward on April 10th. He says, "On ascending the ridge we found the eruption in full blast. Four enormous fountains, apparently distinct from each other, and yet forming a line a mile long north and south, were continually spouting up from the opening. These jets

were blood-red and yet as fluid as water, ever varying in size, bulk and height. Sometimes two would join together, and again the whole four would be united, making one continuous fountain a mile in length." This liquid descended the slope to the grounds about the ranch, then took the Government road, ran down the precipice and followed it to the sea, a "rapid stream of red lava, rolling, rushing and tumbling like a swollen river, and bearing along in its current large rocks that almost made the lava foam." It was from two hundred to eight hundred feet wide, twenty feet deep and had a velocity of from ten to twenty-five miles an hour. The fountains were believed to have reached an altitude of five hundred to six hundred feet and to have thrown up also stones weighing one hundred tons. The ascending lava had a rotary motion towards the south. The stream reached the sea at one point and did not flow after the 12th inst., the life of the river thus lasting only five days. The pahoehoe of the early flow was succeeded by aa which covered 4,000 acres of good pasture land besides much that was of no value. This aa branched out into four wide streams, covering a space estimated at four miles wide and long. The final flow was of the original pahoehoe.

Dr, Hillebrand visited the ground April 23d. He found that the lava issued from a fissure extending about three miles from Captain Brown's house in the direction N. 6° E. up the mountain to a height of 2,800 feet. It gushed out in waves parallel to its course which assumed a direction at right angles to it in the middle of the stream. The edges are somewhat raised above the middle, and much scoria is present, at one place a small cone of scoria about twelve feet high and of equal diameter bridging the chasm. The issuance of hot gases from it prevented a close scrutiny. Near the upper end of the chasm the Doctor was surprised at the sudden apparition of a cataract of lava pouring down an incline of some three hundred feet. The trees and fern stalks were encircled and capped by lava. The extreme point visited was simply a crevice; there was nothing of the nature of a cone of lapilli as was the case at the beginnings of the later flows above Puu Ulaula.

The land runs to a point at the extreme south end of Hawaii, sometimes called Ka Lae and sometimes South Cape. The triangular area—perhaps nine miles long—from the ranch house to the sea, is bordered on the west side by a precipice or pali, suggesting that it lies along the line of a fracture. This impression is heightened by the fact that this line coincides with and adjoins the rent of three miles out of which the lava was protruded. The precipice was known locally as the "Pali of

Mamalu." Mr. Whitney seems to have observed the coincidence in the direction of this pali and the vent of the eruption pointing up the mountain. So did Mr, Coan. In 1886 I visited this locality and called attention to this feature in a letter to Professor Dana, published in his "Characteristics of Volcanoes." "The fissure whence the lavas of 1868 flowed is the exact continuation of the pali up the mountan. I traced it fully three miles. For much of the way it makes a narrow canyon forty to fifty feet wide at the maximum, and so deep that it is dangerous to explore it. In the lower part heat was still evident. The fissure is most prominent where the lava is in greatest amount. Its borders have the smoothed appearance that would result from an outflow of lava over its edge." I have sometimes compared the conditions attendant upon this flow with the splitting of a log of wood. The first blow of the axe splits the log a short distance from the end. A wedge inserted in the split exerts a little pressure, but not enough to continue the enlargement till another blow has been struck by the beetle. A continuance of the blows will eventually split the log from end to end.

Applied to the rent at the base of the mountain, it may be said that the early developments of the force were along the edge of the pali. Ages ago the triangular tract of the South Cape witnessed an elevation after the formation of the fissure had given freedom of movement to the land. There was quite an oasis of rich pasture and sugar land raised so much as to lie above the reach of later lava flows. Hence when the blow was struck later in 1868 the rent was developed for three miles up the mountain, and the lava streams flowed about the oasis upon which the buildings were located. To what extent this fault can be traced up the mountain is unknown, though authors speak assuredly of a rent from the end of the cape to the summit of Mauna Loa. It is interesting, however, to note that the later corresponding eruption of 1887 followed a parallel line of fault several miles farther west.

In the fissure where a little heat was discernible in 1887 there was seen much stalagmitic material containing many crystals of olivine. It must have been a sort of mud, and as elsewhere it and the green mineral came from below in the solid condition. The basalt at Kahuku is unusually rich in this mineral. With this pasty mass there is much clinker and specimens of these materials were obtained very plentifully from this chasm. This rock assemblage is like that exuded on the border of Kilauea-iki at the same date, as is mentioned later. This may be an important fact in the discussion of the relations of the

two great calderas: because this peculiar substance was discharged in these two localities at the same date. It was not restricted, however, to this particular date.

Mr. Coan visited Kahuku and the country adjacent in August, 1868, and has described with great accuracy the features of this cataclysm, as well as the disastrous land slide and sea wave. He climbed to the upper end of the rent, and observed the orifices from whence jets had been thrown hundreds of feet into the air and left behind many ridges and ragged cones of every contour. With partial measurements he estimated the width of the principal flow at one and one-half miles. By uniting all the branches with the main trunk the area discharged would be one and a half miles wide, ten miles long and fifteen feet deep. The course of the flow was due south, and its continuance four days. The amount of matter discharged is small compared with that of 1855.

Mr. Coan adopted the opinion of Judge David Hitchcock that the Kahuku flow came from Kilauea instead of Mauna Loa, at least in part. Coming from an authority second to none among the island observers, many of the residents accepted this deduction; and as the result much discussion ensued. Even upon the map of the islands published by the Government in 1876, under the direction of Professor W. D. Alexander, this flow is said to be "from Kilauea," with an interrogation point.

Rev. E. P. Baker, the successor of Mr. Coan in pastoral duties at Hilo, has well summed up the main points upon both sides of this controversy in the Hawaiian Gazette for August 29, 1883. For the Kilauea derivation, three reasons may be given: (1) At the time of the 1868 eruption the liquid fire all ran out of Kilauea. (2) The earthquakes as reported were more severe at Kahuku, where the lavas finally found vent, than in Kau, (3) The steam vents and fissures below Kilauea, the land slide at Kapapala and the Kahuku rent are on a direct line, supposed to mark the subterranean course of the lava.

Conceding the first two points, the other party explains them by saying that it was probably the terrible shaking of the ground that caused the lava in Kilauea to recede before the time of its normal discharge, and that the efforts of the mountain to let loose the lava were met by a greater power of resistance at Kau than at Kahuku. As to the third point, Kilauea and the steam vents, fissures and small discharges of lava at this time, are on a line different from that of the land slide and Kahuku, being more to the south. The land slide was an accident not connected with any flow of lava. Kilauea has its own field of operations entirely distinct from Mauna Loa.

Two other features are brought forward by the advocates of the derivation of the Kahuku discharges from Mauna Loa. (1) The initial point of the Kahuku flow is from two hundred to six hundred feet higher than the level of the lakes in Kilauea. If hydrostatic pressure is concerned in the discharges, this stream could not emerge from a point hundreds of feet higher than its sources. (2) There is ample evidence of the locality of the 1868 discharge from Kilauea, given upon the authority of Mr. Richardson of Kapapala. Several acres of lava came to the surface at the time of this discharge, located quite near the ejection of volcanic matter mentioned by Ellis in 1823, and other larger ones have been identified by E. D. Baldwin.

In addition to the data brought forward by Mr. Baker, subsequent history substantiates his view. There have been two other Kahuku discharges, (in 1887 and 1907), preceded by earthquakes, attended by similar outpours and closely adjacent to the earlier flow,

January 10, 1870, D. H. Hitchcock, in company with Dr. Hans Beraz and Lord Charles Hervey, ascended to Mokuaweoweo by the way of Kapapala. Steam issued from the banks and floor. There were no indications of recent flows. They rode to the summit; the first time this feat had been accomplished.

June 22, 1870, L. Severance, J. D. Brown and S. L. Austin reported similar conditions at the summit.

MOKUAWEOWEO BETWEEN 1868 AND 1880.

August 10, 1872, heralded the beginning of a remarkable display of lava within the pit of Mokuaweoweo lasting for eighteen months, and no one has reported any discharge of lava connected with it over any part of the mountain or beneath the sea. Mr. Coan saw a lofty pillar of light, two hundred feet high, probably vapors or reflections in part, being sometimes a vertical pillar, an inverted cone and an open umbrella. Seventeen days later there was no abatement in the brilliancy. Mr. Coan wrote that "of all the demonstrations made in this vast caldron on the summit of the mountain since our residence in Hilo, none have equaled this in magnitude, in vehemence and in duration."

August 27th there was a small earthquake wave at Hilo, the water rising during a calm four feet, and in a second wave, six minutes later, three feet, and diminishing for about fourteen oscillations. No one can say with certainty that this tidal disturbance had any connection with either of the volcanoes. J.

M. Lydgate reported the existence of a fountain of fire in the crater in the latter part of August. September 21 the Hawaiian Gazette described the same more particularly—the fountain was in the southwest part of the pit, seventy-five feet in diameter and five hundred in altitude; it was in a basin covering one-third of the lower platform, upon which a low cone formed. It was "a mighty fountain of clear molten lava."

Dr. Samuel Kneeland gives the notes of observations made upon Mauna Loa in connection with its discharges, commencing August 9th, 1872.[21] The names of the observers were W. T. Conway, H. C. Dimond, G, M. Curtis and H. N. Palmer. The location of the jet is not clear, save that the barometer gave it as 14,000 feet, and it would seem to have been near the precipice on the east wall. From the center of a small cone with an apparent diameter of two hundred feet, sprang a jet of molten lava not less than three hundred feet high and about one hundred feet in diameter. There was an opening on the northeast side of the cone, from which flowed a river of lava. which gradually widened into a broad lake, and from the other end of the lake took its course along the base of the precipice which separates the north from the south side of the crater. The fiery fountain was the principal feature; its roar was not unlike that of Niagara, but without the concussion and irregular booming sound of the great cataract. It is hard to conceive the energy of the forces which could keep this heavy molten column in perpetual suspension so many hundred feet high for several weeks.

September 4. Fountain of lava started August 9 was one hundred and fifty feet high in the middle part. Continuous all night.

September 8. Party of thirteen men and a guide confirm the report of September 4. The fountain was towards the west wall in the same place where it has been commonly seen.

On January 6th, 1873, the action at the summit was "marvellously brilliant" as seen from Hilo, apparently that of a fountain. The herdmen at Ainapo represented that the mountain was "constantly quivering like a boiling pot." April 20th the activity was again discernible from Hilo as the light flashed upon the clouds. Rev. A. F. White climbed to the summit May 26th and saw the lava rising from one hundred and fifty to three hundred feet. On the 6th of June Miss Isabella L. Bird and W. L. Green ascended to the summit. For the two days previous no particular action was obvious because of the reflected fire, and they were fearful of being disappointed. When

[21] **Volcanoes and Earthquakes by Dr. Samuel Kneeland.**

within two miles of the crater a distant vibrating roar was audible; and on reaching the pit the roar was like that of the ocean. Most of the floor was an area of solid black lava, but at the southwest end there was a fountain of fire one hundred and fifty feet broad playing in several united but independent jets to the height of one hundred and fifty to three hundred feet. Miss Bird writes: "At night the lake was for the most part at white heat, and its surface was agitated with waves of white-hot lava about the fountain at the center. Through the rest of the vast crater the projecting ledges were thrown into bold relief by the reflected light, and by numerous dashes and lines of fire from apertures and crevices. Occasional detonations were heard, but no shakings except the tremors from the throw and fall of the lavas. At one time the jets, after long playing at a height of three hundred feet, suddenly became quite low, and for a few seconds there were cones of fire wallowing in a sea of light: then, with a roar like the sound of gathering waters, nearly the whole surface of the lake was lifted up, by the action of some powerful internal force, and its whole radiant mass rose three times in one glorious upward burst, to a height, as estimated by the surrounding cliffs, of six hundred feet. After this the fountain played as before. In one place heavy white vapor blew off powerful jets from the edge of the lake, and elsewhere there were frequent jets and ebullitions of the same; but there was not a trace of vapor over the burning lake itself."

Mr. Green, who was with Miss Bird, describes the same scene as follows, having watched it for hours with a binocular: "The fountain generally played to a height of from three hundred to four hundred feet, as estimated from the known depth of the crater, although some spires or shoots would now and then rise to a greater altitude. The form of the fountain would constantly vary, sometimes being in the shape of a low rounded dome, then perhaps forming a sort of spire in the center, with a fountain in the form of a wheat sheaf on each side. Sometimes it would look like one great wheat sheaf. On this day the visible vapors or gas connected with this fountain were quite insignificant; by daylight we could see none, but at night time the bright reflection from the molten lava made visible a light blue haze which quietly left it." * * * "There were two noises which were very easily distinguishable; one was the dull roar of the fall of this fountain of heavy liquid, and the other was the metallic clink of the fall of the solidified lavas which were constantly taken up by this fountain and thrown on to the solid rocks at a little distance from it. Indeed, these

solid pieces and separate portions of the molten lava, which cooled in the air, formed a light falling veil over the dazzling lava fountain, and as it fell close round the sides, it formed a black, level scum which floated on the lava-lake, out of which the fountain arose. Whenever a more than usually solid mass of lava fell within the area of this lake, it seemed to force itself through the black, floating scoriaceous mass and make a golden splash of the white-hot lava beneath it. * * * Away from the fountain white fumes arose like those which often appear in Kilauea."

Mr. Green wrote much more in substantiation of his belief that the fountain was simply a hydrostatic effect with important accompanying vapors.

January 6, 1873, Mr. Coan writes that for nine months the action had not ceased. Its duration is marvellous, considering that it seems to be confined to the crater. There was a special brilliancy to it in January.

June 24, J. M. Lydgate drew a plan of Mokuaweoweo, shown in Plate 17B. Its greatest length is 17,000 feet, or 15,000 without the basin at the northeast. The greatest breadth is 8,600 feet; greatest depth 1,050 feet. The floor is continually rising because of overflows. The lake has a diameter of five hundred feet.

August 27th, Dr. O. B. Adams, Surgeon of the Costa Rica, with his wife, ascended to the summit and found a column of molten lava rising from two hundred to five hundred feet in height, assuming all the various forms of a grand fountain of water.

September 3, R. Whitman and B. F. Dillingham report the jets of lava spouting up a hundred feet.

September 20, W. W. Hall says the floor is covered by lava that was poured out the year previous.

October 6, Mr. Coan says the action has continued for eighteen months, and most of the time it has been violent; but he thinks it will soon cease. There have been few earthquakes, and those feeble, during the year. Kilauea has been unusually active all this time.

In October Messrs. E. G. and H. R. Hitchcock reported similar conditions. The fountain played to the height of six hundred feet, as determined by lying upon the brink and looking across the pit to the top of the opposite wall, estimating to what point in the wall the top of the column was opposite. The descending lava flowed off northward nearly the whole length of the western side of the pit.

Similar eruptions were evident in 1875-6, Mr. Green mentions the occurrence of summit action January 10th, lasting for one month. He regarded these fountains in 1872, 1873, 1875 and 1876 as premonitory of the great outbreak of 1877. On August 11th, 1875, Mr, Coan reported the summit crater as again in brilliant action, lasting for one week. About this time a party from the Challenger Expedition reported the presence of a "globular cloud" on the summit, which was "perpetually reformed by condensation," and had a brilliant orange glow at night looking as if a fire were raging in the distance."

It is reported that during this year Mr. George Forbes succeeded in finding a path to the summit without passing over any aa.

Another grand display of short duration was reported by Mr. Coan on February 13, 1876.

SUBMARINE ERUPTION IN 1877.

On the 14th of February, Mr. Green reported that from a "great vent on the flat top of the mountain there burst forth smoke and white-hot molten lavas" which lighted up the whole Island of Hawaii and was so bright on Maui as to cause people to believe that large sugar mills were on fire, which happened to be between them and Mauna Loa. Mr. C. J. Lyons being at Waimea, thirty miles north, estimates "that the smoke masses were ejected to a height of not less than 16,000 feet above the top of the mountain, where they hung, forming a dense stratum. The velocity with which they ascended was such that the first 5,000 feet were passed inside of a minute." Mr. Coan estimated the altitude at from 14,000 to 17,000 feet and stated that this brilliancy lasted for only ten days. On that last day a submarine eruption manifested itself, accompanied by an earthquake, a mile from the shore off Kealakekua. A crevice was made on a line between the summit and the site of the submarine eruption, extending inland for three miles. Rev. J. D. Paris has stated that the natives reported fumes of sulphur and red-hot lava in fissures up the mountain side.

This eruption, about three A. M., February 24th, displayed red, blue and green lights, starting in very deep water, at what seemed to be a pali, and so it was at the intersection of two fissures according to Mr. Green. Mr. H. M. Whitney says that blocks of lava two feet square came up from below, frequently striking and jarring the boats. The pieces were soft, red-hot, emitting steam and sulphurous gases. As soon as they

became cold they sank out of sight. Another account says that some of the blocks were hard, as evidenced by the breaking off of a large piece of copper from one of the boats. About this time an earthquake wave was reported by Mr. Coan on the Kona coast. The coincidence of so many seismic phenomena makes it probable that there must have been a submarine discharge which relieved the pressure exerted by the column of molten lava in Mokuaweoweo.

MOKUAWEOWEO IN 1880-'81.

Professor W. T. Brigham ascended Mauna Loa from Ainapo the last of July, about three months before the celebrated outbreak of 1880-'81. Fire had been seen in South Mokuaweoweo May 1st. Ahuai, the guide of so many scientific men to the summit, reported that the fire at that time was a fountain, which rose to the level of the rim of the pit, so that it was seen by him as he was lying down at some distance away. As the pit is eight hundred feet deep this jet must have been very notable. Mr. Goodale confirms this statement by adding that the lava was thrown sixty or eighty feet above the brink of the crater, where he was standing. On the same day flocks of Pele's hair were carried from the summit to Hilo. Mr. Brigham found the path from Ainapo worse than the one he took on foot on the opposite side of the mountain in 1864, because of the presence of numerous fragments of scoria from one to twenty feet in bulk. On the summit there were abundant deposits of the vesicular lava called limu, of a pale green color, a frozen froth. He found little change in the general aspect of Mokuaweoweo, save in the tendency of the lava blocks to fall—as they seemed like a wall of loose stones laid artificially. In 1864 he had seen two cones in the bottom of the main pit near the eastern wall about two hundred feet high, which were not noticed by Mr. Luther Severance in 1870. At the end of the trail up the mountain from Ainapo, Mr. Severance had estimated the depth to the floor at one hundred and twenty feet. On the west side there were sulphur beds.

With the plan of Mr. Lydgate before him, Professor Brigham states that the changes in the walls were insignificant, but the bottom was covered by fresh lava. He could not ascertain the source of this lava, but suggested that it might have been collected from inclined lava jets from the walls, spouted out clear of the crater. As considerable heat was manifested from the cracks on the sides of the mountain, Mr. Brigham believed that a great eruption was on the way—

as was demonstrated on the 5th of November following. Mr. H. M. Whitney, writing from Kau, May 12, states explicitly that this eruption commenced as quietly as moonrise, without any premonitory shakes or noises; but we have the following from W. H. Lentz, in the record book of the Volcano House:

May 1, 1880. At 9 P. M. the large crater on top of Mauna Loa burst out as a large lurid light with a roar resembling thunder. At 10:05 P. M. there was an additional eruption from the crater to the north of Mokuaweoweo, apparently as large as the first. At 11 P. M. there was still another; this time southwesterly from the first, making in all three active fires on the top and slopes of Mauna Loa. Kilauea is also very active; both lakes are booming and a third forming. There are several large flows on the floor of the crater.

Later, under date of November 5th, he records as follows:

About 9 P. M. a flow of lava started from the northern slope of Mauna Loa, apparently towards Waimea; and on November 9th the same flow started a branch along the slope and fall of the mountain toward Kapapala, which continued several days on its journey, making eight or ten miles per day.

Mr. Coan states that the first light of this eruption was seen at Waimea; later from Hilo. "The lavas could be distinctly seen leaping like a fountain into the air."

The source of this stream is along a divide, although the ground is very flat. A fissure is still traceable along this divide running N. E. from Mokuaweoweo. After considerable difficulty the Government map located the terminal crater for this flow near Puu Ulaula and quite near the source of the 1852 and 1855 flows. I have examined the small crater of lapilli from which the flows proceeded. The light was first visible from Waimea, November 5th, 1880, and a few hours later from Hilo, from whence a fountain was visible. The source was about 11,000 feet above the sea. The next day a line of light extended from this source toward Mauna Kea. About the same time another stream started from the same source and proceeded towards Kau; and again later a third stream commenced a little lower down and proceeded toward Hilo. The Kea stream flowed to the saddle between Mauna Loa and Mauna Kea, about twelve miles. The Kau stream coursed southerly about the same distance. Rev. E. P. Baker finds upon repeated examination that the first two streams started from a pit crater known as Puka Uahi, exactly upon the divide, so that a very slight obstacle turned the stream from one side to the other, He

says the Kau stream started first, the Kea next and the Hilo from a still lower point.

Judge D. H. Hitchcock saw the second and third streams on the 11th inst., from Kalaieha, already several miles in extent. Half way from the plains to the source the lavas rose into a large dome, over which it flowed like a fountain. Mr. Green says that several orifices discharged lava "accompanied by the usual white-hot lava fountains, brilliant reflections and immense volumes of smoke." These streams varied in width from a few yards to several miles, and there are separate areas several square miles in extent from ten to twenty feet thick. The cubic contents were not equal in amount to those of the 1855 flow. The greater part of the lava came out in the first few weeks of its history. In four months' time the Hilo stream was about twenty-six miles long and within seven miles of Hilo; in seven and two-thirds months, June 28th, within five miles; July 18th, about two miles; and August 10th, nine months after the outbreak, the stream stopped at a stone wall near a sugar mill, three-fourths of a mile from Hilo. June 30th, the velocity was measured and found to be seventy-five feet an hour. Had the flow been concentrated in one stream the town of Hilo would have been covered up. The people were very anxious, as was natural, and made use of divination and prayer to the higher powers for relief. Sorcerers or priests supposed to be representatives of the ancient Hawaiian regime attempted to stay the flood near the house of John Hall, The stream destroyed the house but left a small part of the garden and continued its general course. Prayers were offered continuously by the church, and it was believed that these supplications had led to the removal of the threatened calamity.

A series of eight photographs has been widely circulated, showing how a stream of water was licked up. The first displays a group of people standing at the edge of a cliff while the lava had nearly reached the brink behind them. Soon the people disappeared and a little of the sanguineous fluid crept over the bank. This increased, became a steady cataract, the water turned into steam, explosions ensued. The basin was gradually filled up and became a gently sloping plain in the space of one hundred minutes. At a similar locality the lava was cooled at first and large pieces accumulated in piles as high as the cliff; then the lava stream flowed directly over the talus and the water flowed side by side with the lava until it had been evavorated and the basin filled up. This was fresh water. I have seen one of these illustrations engraved in a book and it was said to be the flow of the stream into the ocean. In our his-

PLATE [illegible]

Stalacites in lava flow 1881. Cave at Bougainville.

torical sketch several cases have been mentioned where the flow of lava reached the sea, but not this one. Plate 24B illustrates the movement of the lava over a cliff into a pool of fresh water.

The Kau stream is mostly aa, but started as pahoehoe. Most of the Hilo stream is pahoehoe. About four miles from Hilo there was a change from pahoehoe to aa, and one can pass for many rods through a tunnel in which the molten lava had flowed for a long time—the entrances being where the roof had fallen in. There are stalactites, stalagmites and various mouldings. Some of the surfaces are glazed. The tunnel is very variable in its dimensions, from two to ten feet high with a general width of thirty feet. The roof is from two to six feet thick. I have a view painted by Furneaux of the lava stream, intensely hot, coursing down the slope, but visible because of a break in the cover. Stalactites of peculiar shape abound: some are as slender as pipe stems, of uniform width, but very much twisted; others are straight with a short, irregular twist near the end. Mr. Baker found some bent toward a blowhole entrance into the tunnel. Some are from twenty to thirty inches long, and usually six or eight inches apart. The stalagmites beneath consist of a heap of similar bent coalescing stems. Crystals of olivine are common in them. Other stalactites are short and thick, often resembling the udders of mammals, and have a glazed surface. Stalagmitic masses frequently are like piles of ordure. Some of the stalactites show that clots of the liquid lava were thrown about and lodged upon them near their points. Plate 20 is a photograph of a cave near Bougainville showing the stalactites hanging from the roof and the stalagmites beneath upon the floor. It was found in 1881 and was taken by Professor W. Libbey of Princeton in 1893.

The three streams connected with this eruption are delineated upon the general map of Hawaii, Plate 14.

MOKUAWEOWEO IN 1882.

Captain C. E. Dutton ascended Mauna Loa in 1882. First he visited the group of cones near Puu Ulaula, the sources of the later flows, 1855, 1880 being among those which he identified. Each one is a true crater, composed of lapilli and ashes which were ejected when the several streams of lava poured out successively. None exceed one hundred and twenty feet in height. He justly represents the dominant idea of the area as immensity, whose best conception is attained by attempting

to journey over it. Miles may be traversed and yet the same landmarks seem to stand just where they were an hour previous.

Because of the arrangement of the rough lavas one cannot well continue on from Puu Ulaula direct to the summit with animals, so the descent to Ainapo is necessary before attempting the summit. This he describes as a broad platform about four or five miles in extent, within which is sunken the caldera Mokuaweoweo. It is about a mile and a half from the shoulder of the mountain to the pit. The surface is more rugged than the slopes passed over. Cracks and piles of broken rocks (but no cinder cones) are everywhere apparent.

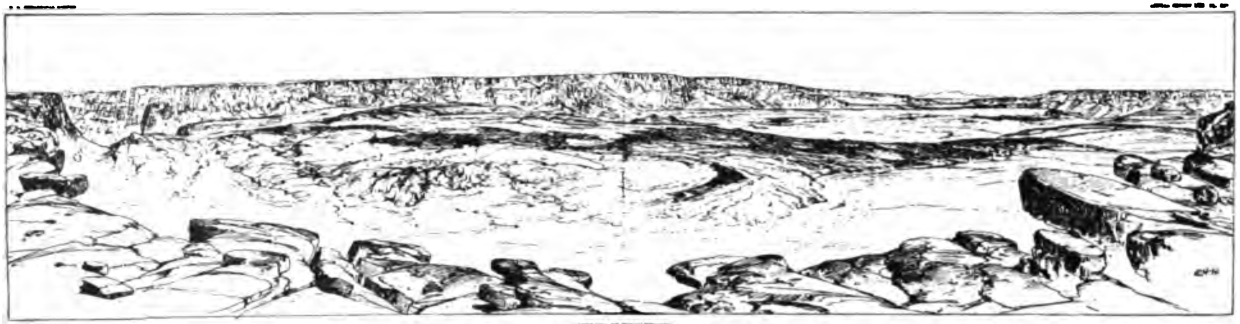
At the east edge of the pit the wall is about six hundred feet deep. The view is more impressive than that of Kilauea, because the depth is greater and the encircling walls are more precipitous and continuous. The floor is covered by the same hummocks and broken crusts. In the central part there is a depression suggesting the lower pit of Kilauea and the surrounding black-ledge. Captain Dutton had Lydgate's map of 1874 before him and seemed to consider the central area as the lower pit, one hundred and seventy-five to one hundred and eighty feet below the platforms both to the north and south.

There was no volcanic action whatever; not even a wisp of steam could be detected issuing from any point. The lava lake had become as solid as the rocks of the walls. Still he does mention some heat rising from the numberless little cracks upon the floor, and an occasional whiff of sulphurous gas. Looking at the panorama outlined by W. H. Holmes from Dutton's photographs, Plate 18, one perceives that the main foreground is the southern platform (C of Alexander's map). Directly in front near the west wall is the "boundary cone" in front of gravelly fans that may represent eruptions from fissures. To the left there is the descent to the small southern crater. The main pit to the right appears much smaller than it is, because of its distance. Near the east wall is a small double cone. The edge of the northern platform is quite irregular, and in the far distance are the outlines of Mauna Kea.

ASCENT IN 1883.

The writer was privileged to follow the trails taken by Captain Dutton to the sources of the 1880 flow near Puu Ulaula and to Mokuaweoweo. His companion was F. J. Perryman of the Government Survey, and the time was January. Following

PLATE 18.



Panorama of Mokuaweoweo.

so closely to Dutton, our observations could not vary much from his. The trip has been a great help in the understanding of the phenomena attending the later eruptions; and some reference may be made to what was seen by us in 1883 in the sequel.

Our experiences on the summit of Mauna Loa were somewhat unique. Because of the presence of snow our guide completely lost his way. The Hawaiians remember every crag and fragments of rock along the route, as they are landmarks. But the snow had completely concealed everything upon which Ahuai relied for information, and we found ourselves walking in a circle. We had just determined to find our way out by the compass, when Ahuai fortunately descried the pit, and we had as good a view of the caldera as the season permitted. My point of view was the same with that showing Dutton's panorama. Just before reaching the edge of the pit a snow squall struck us, charged with electricity. All of us in the party emitted electric sparks from our persons, with a prickling sensation. The feelings were such as I have experienced when holding the cups of a magneto-electric machine. Mountaineers have occasionally passed through similar experiences in highly elevated regions.

The fresh snow gave us a view never before reported from the summit. The platform beneath us, probably only the limited shelf which occupies so much of the foreground in the panorama, was white with snow. Hence the volcanic peculiarities were concealed from view. But the fact that snow could exist there in the short time we had to observe corroborates Captain Dutton's statement of the absence of all signs of igneous action. The volcano was so dead that snow could rest upon it for a time without being melted.

MOKUAWEOWEO IN 1885.

E. P. Baker descended to the bottom of the crater in April and found everything quiet.

One of the most satisfactory reports of the conditions in Mokuaweoweo is given by Rev. J. M. Alexander, who was engaged in surveying lands for the Government, and marked the corner in the bottom of the pit where the four areas of Keaauhou, Kahuku, Kapapala and Kaohe meet, which is at the cone in the southwest part of the principal pit. This principal pit had a floor of pahoehoe streaked with gray sulphur cracks, from hundreds of which there issued columns of steam, and the boundary cone (M) one hundred and forty feet high, composed of pumice and friable lava, still hot and smoking. Just east of this cone was a basin (E) four hundred feet wide,

twenty feet deep, apparently connected with a recent flow of lava to the northeast. South of the boundary was a plateau from five hundred to five hundred and fifty feet below the summit (C on the map) and beyond this an opening into a small deep pit (D) eight hundred feet deep. North of the main pit was another shelf six hundred and seventy-five to seven hundred and fifty feet down (B on map), rising from the lower floor by a precipice of fifty feet. At the north end the highest plateau (A) four hundred and seventy-five and five hundred and fifty feet had practically the same level as C. The easiest path down was at the south angle of A just south of a circular pit six hundred feet deep, 1,000 feet wide, with a cone in its center still smoking. Not very long before there had been a flow of lava from the summit into A making the incline for the path down. "Farther south there were the courses of two other cataracts, which had poured directly into the central crater. At the summit I found the deep fissure from which these cataracts had been supplied with lava, and ascertained that it had also poured an immense stream north upon the first plateau and thence south into the central crater."

The length of the whole caldera was about 19,000 feet; the greatest breadth 9,000 feet; the greatest depth 800 feet; the area 3.6 square miles. Near the north edge of plateau C, south from the boundary cone, there had been eruptions from fissures both into the plateau and to the southwest towards Kahuku.

Of the general conclusions Mr. Alexander opines that Mokuaweoweo is a series of four or five craters, the walls of which have broken down, so that they have flowed into each other.

Finding that lava had flowed into the caldera, he asks: "How has the lava risen high enough to pour in extensive eruptions through these fissures, almost a thousand feet above the bottom of the crater, without rising in the crater and overflowing it? The same question has often been asked in respect to the rise of liquid lava to the summit of Mauna Loa without overflowing the open crater of Kilauea, 10,000 feet below."

The smaller craters, more than fifty in number, on Mauna Loa, Mauna Kea and Hualalai are arranged without reference to the several mountains, but to points of the compass. The nearly parallel fissures through which the lava has flowed with craters run from S.40°-60°E. There are a few arranged in lines running N.50°E. The major axes of the great craters upon Hawaii are at right angles to the general trend of the archipelago, or about N.30°E.. The highest walls are on the western side, and the action is developing towards the southwest.

Mr. Alexander made his first ascent in September, 1885, in company with Mr. J. S. Emerson, passing by the ragged crater hill from which the outbreak of 1859 had issued. His other journey, when he completed his measurements, was about a month later. Plate 17C is a copy of J. M. Alexander's map.

ERUPTION OF 1887.

This was like that of 1868, and broke out low down the mountain at Kahuku. In December, 1886, earthquakes became frequent about Kahuku. These averaged three per diem by the 12th of January. Mr. George Jones counted three hundred and fourteen shocks between 2:12 A. M. of January 17th and 4 A. M. of January 18th; sixty-seven on the 19th inst., and three on the following day. In Hilea six hundred and eighteen were counted between 2 A. M. of the 16th and 7 P. M. of the 18th. Other persons counted between five hundred and six hundred in the two days and then desisted because the shaking became almost continuous.

Light appeared in the Pohaku o Hanalei south of the summit about 9 P, M. of the 16th. It was also visible from the 18th to the 20th. Mr. Baker found the height of the first outbreak on the 16th or 17th to be 11,500 feet. There did not seem to have been much action in Mokuaweoweo. About 4 P. M. of the 18th, with the culmination of the earthquakes, there came an outbreak about 6,500 feet above and twenty miles from the sea, consisting of fountains of lava rising up from an extended fissure. The flood reached the sea at noon of the 19th about four miles west of the flow of 1868. It extended from three hundred to five hundred feet out to sea without making any cinder cone. By noon of the 24th inst. the flow ceased, but fires were still active along the vent. January 20th, parties visiting the spot counted fifteen lava fountains, some of them two hundred feet high along the line of fissure N.30°E. for two or three miles. Mr. Green says this lava flowed for fifteen days, the latter part of the time under its own cooled crust, and formed an aa stream from four hundred feet to two miles wide, and from eight to twenty feet deep.

I abridge the following statement from the account of W. E. Rowell, C, E., of Honolulu, who visited the flow January 23d. At the height of 3,400 feet the stream was an open river with well defined banks more than one hundred and fifty feet wide, running at the rate of six to eight miles per hour. The stream was filled with lumps or grains occasionally carrying black blotches upon its surface. At the height of 4,000

feet there was an immense fountain, rising between walls of fresh lava which had become consolidated, from fifteen to forty feet high. The lava spouted up like a jet of steam, whose spray fell to the ground, solidified with lapilli. The main fountain occupied a length of more than one hundred feet along the channel. Two other fountains were also observed, one above and the other below the one first seen.

Rev. E. P. Baker visited this flow on the 28th inst. with others. They found the head of the flow 5,700 feet above the sea, sixteen miles by pedometer from Jones' Ranch and above the timber among sparse ohia. It had formed five small cones in the line of a fissure at least three miles long. They saw a fountain playing one hundred and fifty-five feet high from a cone fifty feet high, falling into a basin of lava from whence issued a narrow stream of pure white fire twenty-five feet wide, with a velocity of fifteen miles per hour, Much lapilli was thrown out.

Professor Dana reports from various accounts that the lavas were thrown up as fountains, about eighty feet in diameter and one hundred feet high. One authority, Mr. Spencer, says that on the 20th there were fifteen fountains in action, the highest rising to two hundred feet. Blocks of stone weighing tons were moved by the stream. At first the stream was of aa, flowing about one and a half miles per hour. Later the flow was rapid and consisted of pahoehoe. The throw of the earthquakes was to the southeast, and light wooden houses moved eight or ten inches down the slope. In Hilo the oscillations were said to have been from the south-southwest. February 20th, Judge D. H. Hitchcock was at the summit and found vapors issuing from large fissures.

From Rev. S. E. Bishop's description in the Hawaiian Gazette, we quote the following. He arrived off the flow February 1st after the lava had mostly ceased running:

"At daylight we steamed in some six miles from where we had lain around in the night, The same dark cloud kept its station, marking the course of the hot flow directly beneath it. Mauna Loa's vast dome, now cloudless, was far inland, but dim in the haze. To the right stretched away the long, low south point of the island. Inland, about six miles,, the groves and buildings of Jones' Ranch broke the line of the long slope. Close to this could be seen the black line of the pahoehoe flow of 1868, terminating broadly at the sea near Marchant's hill, two or three miles to the right. In front were other and older flows, among which, broader and blacker than the rest, spread-

ing lawless and ragged down the strong slope to the level bottoms, lay hot and tumultuous the flow of 1887.

"The hot air over the flow rises in a strong current. At the height of perhaps 3,000 feet from the surface it rarifies and chills, condensing the aqueous vapor with which all air is loaded, thus forming a dark, massive cloud directly over the flow and marking its course. Some seven miles inland this line of cloud made a sharp turn or elbow to the northward, directly toward the summit crater of Mokuaweoweo. We had the pillar of cloud by day, but to our chagrin, we had not pillar of fire by night. Noting the length of this cloud, and where it appeared to terminate, I estimated the length of the flow at from sixteen to twenty miles, and the head of it very much more than twice as far inland as Kahuku Ranch.

"The front of the new lava was easily distinguished as we steamed up to it by its black and rugged piles and outjetting points, in contrast with the whitish, mossy sea line and older rocks on each side. From most parts of its shore small clouds of steam were rising thickly. From a cone near its south side a large jet of strong steam rolled continuously and clouds of this swept up on land. Hereabouts for fifty feet out from shore the water was covered with visible steam. We stopped near the south side, dropped our boats and rapidly landed the whole crowd of two hundred visitors, including natives. We climbed up the rocks some twenty feet upon an old pahoehoe flow. This was a mass of hummocks, wrinkles and bubble caves, but quite easily clambered over. Many large sea-worn boulders and much sand had been flung up one hundred feet or more inland over this by the tidal wave of 1868. A lauhala grove was on one spot of sand, and the green streamers of the maia pilo lay in profusion on the lava with their great, lovely plumed white flowers.

"But to the left the vast, hideous mounds of Pele's awful work enchained our eyes. like enormous piles of brownish coal, but indescribably more ragged, stretched inland over the low rising plain for two miles to the mountain slope, in a substantially direct line, this bank of hot cinders, averaging twenty-eight feet high on the edge, but rising towards the middle to an average height of forty feet. Many points must have been twenty feet or more above the general level, if the word level can be used of such chaotic masses of ruin. The sides of the mass were steep and crumbling, composed of large, ragged clinkers and fine cinders intermingled, difficult enough to climb on its jagged but yielding footing. The whole seemed like a colossal embankment, as if 10,000 cyclopean trains of mastodon

cars had been dumping the rocks of Mauna Loa for a century towards the sea.

"All was shimmering with heat. We found a way up the crumbling heaps of pumice and slag, and reckless of singeing boots and hot blasts from below, scrambled around among the sharp and ragged pinnacles to higher points, whence only a wider waste and wilder desolation were to be seen. At one point a party were charring their sticks in a red-hot hole. At another was a rent fifty feet long, where, some fifteen feet below, was a great glow of almost white heat along its length. There was almost an entire absence of noxious odors and gases, and even of steam, though sudden hot blasts of air would often drive one aside.

"The sea front was most impressive. Here the great embankment rolled over the cliff some twenty feet, making slopes of from fifty to seventy feet high from the water along a shore of from three-fourths to a whole mile in length. I consider it certainly not less than the former distance. The sea front is broken into a succession of long, ragged capes and deep coves, with many wide beaches of coarse, black gravel, thrown up by the waves, looking like shiny nut coal. Here and there huge round boulders, bristling with adhering cinders, lay half buried in the ragged slopes. One of these was visited and found to be twenty feet long. Are they fragments of the mountain's massive throat torn by the outrushing flood, which half melts and rounds them?[22] The water near the shore was generally from one hundred to two hundred degrees Fahrenheit and in spots much higher and steaming.

"The northwest side of the floor presents a straight solid embankment, apparently thirty or forty feet high, at an angle of 40° to the coast line, stretching northward for apparently a mile or more, then turning inland. Evidently the breadth of the stream is fully one and a half miles at a short distance inland. I judge that on the lava slope are deposited three square miles of clinkers, thirty or forty feet in depth. The flow evidently overreaches the original coast line from two hundred to five hundred feet, making some thirty acres of new land. Much of this last is of great depth, soundings being from twenty to thirty fathoms close to the shore. A large or rapid extension of coast is impossible where such a depth is to be filled in.

"It is comparatively easy to estimate the amount of forces involved, and the colossal dimensions of the great tidal wall of mingled white-hot lava and scoria foam that rolled so steadily

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[22] These were aa bombs, comparable to a turnover pie of clinkers wrapped in an outer crust.

Flow of 1887. Mauna Loa.

and massively forward to the sea, which it first reached more than two weeks before. One can perhaps partially imagine how that tide of fire and rocks of near a mile wide rolled for a week over the shore into the deep and convulsed ocean. But I have never seen work of that sort, and I have no powers of imagination to conceive the awful splendor of the downward charge of that mile-broad deluge of fire, nor the horror of tornado clash and roar with which that vast wall of rolling rock and cinder pressed forward over the land, piling upon the plain, crashing into the sea. We saw but the dead and dying remains—dreadful, dark and silent.

"The lava in its descent appeared to be making aa exclusively. Pahoehoe was seen, however, mingled in some portions of the flow visited. The lava was bright on Sunday night, the 30th, as seen from the Kahuku Ranch near by and much glow was visible on Monday morning. * * * I can add no more of special interest about the eruption of 1887, except that it is unquestionably much greater in quantity than that of 1868, being more than twice the length of the latter, and of greater depth on the ground." Plate 19 represents a part of the flow of 1887.

Dec. 29, 1887, J. S. Emerson from Kohala sees volumes of smoke and steam pouring out of the summit crater, but no glow or reflection of fire. These signs of activity disappeared early in February following.

VISITS OF W. C. MERRITT AND E. P. BAKER IN 1888.

Most of the features observed by Mr. Alexander in 1885 were recognized; but the depth of the east wall seemed to be only three hundred and fifty feet instead of eight hundred. There were fissures at the very south end of the caldera pointing towards Kahuku, or the eruption of 1887. They descended into this pit finding its depth eight hundred and seventy-five feet, and saw some very fresh looking lava which may have been poured out the preceding year.

The trip was made in July. Mr. Baker saw seven running streams and three or four ponds of water in going from Ainapo to the source of the 1887 Kahuku flow.

July 29, 1890, L. A. Thurston and Mr. Clark descended into the pit and saw a blow hole still warm, and considerable steam. The floor was covered with pumice. At the southwest corner a dense column of steam arose which was not wholly dissipated till it had risen above the rim. There was much sulphur at its base and higher up on the west wall.

June 24, 1893, Julian Monsarrat, E. P. Baker and five others, besides the Hawaiian guides and helpers, visited Mokuaweoweo. Mr. Baker refers to the disappearance of a small crater two hundred feet in diameter and two hundred feet deep, which was found on the floor of the main crater in June, 1887. He had seen it in 1888, and Mr. Monsarrat saw it in 1889. In 1893 it had been obliterated, having been filled by the lava continuous with the general floor.

MOKUAWEOWEO IN 1896.

Dr. Friedlaender had visited Vesuvius and Etna several times and was familiar with volcanic scenes. He had also visited the summit caldera in 1893, when it was inactive.

April 21, 1896, when in Kona, he noticed a large white cumulus cloud very high up on Mauna Loa, and in the evening from Honomalino a bright fire reflection. He ascended from Napoopoo, starting from the house of Mr. John Gaspar with his host and Charley Ka for guides. The start was on horseback, April 25th. They ascended through the forest to the height of 7,500 feet, where the horses were left behind; though it seemed possible to use them nearly to the summit, after some knowledge of the route had been obtained.

The cloud over Mauna Loa was a cumulus of the well known shape of the Italian pine: a large mass of vapor floating to an enormous height and connected with the mountain only by a narrow trunk of smoke. "The afternoon sun illumined the cloud; its snowy white slowly turned yellowish, then, about sunset, crimson, and soon the volcanic glare became visible; first the narrow pillar, then the whole cloud formation becoming aglow from the incandescent matter beneath."

The vegetation dwindles at about 3,000 meters; at 3,500 meters it had disappeared, and it was possible to choose pahoehoe instead of aa for the path. At the height of 13,000 feet the mule and attendants were left. The summit plain is almost level, and the opposite side is first visible.

It was easy at this time to compare Mokuaweoweo with Kilauea. Both are of nearly the same shape and size. The longer diameters have the same compass course. Both have their highest points upon the west side; and the walls are nearly perpendicular and the places of the most comfortable descent are on the N.E. and S.W. corners. The area of Mokuaweoweo is smaller and the walls higher than in Kilauea. Also the lava lakes are situated similarly near the southern walls.

The lava lake was "very large," almost level with the general

floor, surrounded by low vertical walls. The surface was crusted over and then broken up into numerous blocks as has been described for Halemaumau. There were two large and one small lava fountain, the former of which played regularly and uninterruptedly. Their height was estimated to be forty-five to fifty feet, their temperature was very high as it was possible to use the light for photography in the night. The full moon and the fountains affected the photograph plate almost alike. Dr. Friedlaender did not descend into the pit. He believed that the lavas of the higher crater contained more gases and had a higher temperature than Kilauea. He suggested that this supposed fact would tend to explain the enormous differences of level between the two volcanoes. —From Thrum's Annual.

Several gentlemen visited Mokuaweoweo while this eruption was in progress, and one of them, Daniel Logan, has written the following statement of some of the interesting phenomena seen. The lake was said to be 2,000 feet long and 1,500 feet wide. "The fountains of Mokuaweoweo are different from those of Kilauea when in activity, in that they preserve their relative positions toward each other and their environment, besides being in constant and uniform action. When I say uniform I mean that, although their ebullitions are varying in violence, as well as in height of projection, the changes proceed in steady alternation and there is never a moment of total subsidence. In the lake of Halemaumau the fountains were constantly changing in position and number both, and sometimes for several minutes the entire surface will be crusted over, showing scarcely a streak of fire. The forms assumed by the fountains of Mokuaweoweo are of exceeding beauty. Each one shows a multiplied facade of spines composed of thousands of bunched jets of orange color, the spine to the extreme left the tallest and the others—perhaps eight or ten—diminishing to the right. The component jets fall inward, when their upward impetus is lost, in graceful parabolas excepting when, at every major ejection, there is a fierce explosive-like projection outwardly from the main spire. The whole effect is that of an illuminated Gothic cathedral's front. In ascent the velocity of the ejection is that of a rocket multiplied. Stupendous projective force is what impresses one together with the extraordinary pyrotechnical beauty of the display. At the bases of the fountain there is an intermittent boiling and surging, and a sullen roar of awful majesty rises and falls like that of the ocean beating on a rock-bound shore. The jets are intermingled with a profusion of dark angular projectiles, giving the appearance of a shower of brick as they fall, which I am informed is pumice

stone. In line with the large fountains are small ones—merely miniature in comparison—which play at frequent intervals like those of Kilauea, right out to the edge of the lake. There is a steady aa flow from the fierce caldron—which is fast covering a deposit of pahoehoe. * * * We see its outer edge being pushed slowly but surely by the grinding and rolling mass behind toward the lower bank beneath us. The van of the movement is marked with crimson fire, and the whole area of the flow is streaked and dotted with similar evidences of fiery vitality. While we are gazing in raptures on the spectacle, a phenomenon of wonderful interest, noted by observers of previous eruptions, is repeatedly witnessed. The heat produces a fierce whirlwind at the opposite side of the crater. It is shaped like a pillar, slender and pale brown, high as the cliff opposite, or a thousand feet, and symmetrical as a Corinthian pillar. At is rushes along at galloping speed, with a spiral motion, its lower end rips up the massive lava crust in huge slabs and tosses them aside like the action of a steamer's propeller in friable ice. * * * The height of the fountains is estimated at five hundred feet.

April 29-30. A party of fourteen persons with two guides and three helpers, made the ascent while the conditions were interesting. Mr. F. S. Dodge marked the peculiar features of the eruption upon a copy of the plan of Rev. Mr. Alexander. The new lava covered about half the area of the main pit. The fountains of lava occupied the place where they have always been reported; and there was a deep pit near the south wall. They did not descend to the lower levels.

In 1906 Mr. H. B. Guppy, an English Naturalist, published an account of a three weeks' sojourn upon the summit of Mokuaweoweo, Aug. 8-13, 1897. The air was highly electrified. He could trace letters upon his red blanket at night in phosphorescent lines. The air was also very dry, leading to the following physiological effects; cessation of the action of the skin, severe headaches, sore throat, tendency to palpitation, dyspnœa, sleeplessness, lassitude and loss of appetite. Most of the unpleasant symptoms disappeared when damp weather intervened. Just before sunrise and after sunset the shadow of the mountain was thrown back against the sky. The range of temperature was twice as great as on the coast. He made many descents into the pit on the northwest side. In dry weather smoke issued from near the center of the pit and in the southwest corner, where are deposits of sulphur, and whence moist vapors arise from nearly the whole surface. These are white, and are supposed to be rising all the time, but are invisible except when there are clouds over-

head or it is damp. Very much vapor discharged from South Mokuaweoweo, which is the "smoke" sometimes observed from Kona. Insect life is abundant, having been brought up by a southerly wind.

Mr. Guppy made important observations upon the history of the caldera during his sojourn on the summit, which were published in the *Advertiser,* September 6-8, 1906. The great antiquity is proved by the slight differences of contour shown since 1840, as well as the depth—at first seven hundred and eighty-four and in 1885 eight hundred feet.[23] There have always existed the great central cavity, the north and south banks and the pit that has been termed South Mokuaweoweo. The small pit at the north end must have existed though it is improperly located upon Wilkes' plan and is not specified upon Lydgate's sketch, but was spoken of by Dutton in 1882. The crater-producing processes now operating in the caldera are the formation of lower pits either in the main cavity or the adjoining areas, the continual lateral enlargement of the principal depression by slips from the sides and the occurrence of two areas at the northeast and southwest where there is a constant discharge of aqueous vapors. None of the pit-craters contain ejected materials heaped up at their borders, but Pohaku Hanalei, about a mile southwest of Mokuaweoweo, is formed of lava ejected in the molten state and loose blocks, making a cone two hundred feet high, and its base five hundred or six hundred feet below the caldera.

His views of the origin of the caldera are briefly summed up as follows: "It would seem that Mauna Loa has been raised over a deep-seated fissure running N.E. and S.W. for a distance of at least ten miles, and quite independent of the focus of Kilauea. This huge mountain presents in the great terminal basin of Mokuaweoweo evidence of its own decay as a volcanic vent. After the coalescence of the line of pit craters on its summit, its condition was doubtless comparable to that of Kilauea in our own time. Then with the defervescence of its activity, the level at which the lava was maintained in a permanently liquid condition fell lower and lower until it lay as it does now, several thousands of feet below the summit. From time to time, however, there was recrudescence of volcanic heat resulting in the rise of the level of the permanently liquid lava towards the summit, the solid floods of the terminal craters reliquifying with the access of heat, whilst the crater walls were continually undermined by the partial remelting of their foundations. During the periods of quiescence

[23] Add to these figures those of Menzies of 1,200 feet in 1794, of Douglass of 1,270 in 1834, and of Dutton of seven hundred and eighty in 1882.

the great basin grew in breadth by the rifting and falling in of its walls, and the products of its own decay were remelted as they lay on the floor during each recrudescence of activity. It is in this condition that Mokuaweoweo presents itself at the present day."

In the study of the spring waters in the southern part of Hawaii Mr. Guppy finds facts that sustain the proposition that Mauna Loa and Kilauea are separate centers of influence. "As far as the temperatures of the underground waters can guide us, we are able to distinguish on the southeast coast of Hawaii between the respective zones of influence of Kilauea and Mauna Loa. The thermal regions of the two zones are sharply contrasted. Along the whole length of the south coast of Puna, beginning at the modern lava flow that reaches the coast at Keaiwa, about half way between Punaluu and Kapapala Bay, the underground waters of a greater or less degree display a temperature increased by the vicinity of volcanic action. This is the Kilauea zone of influence, and the excess of heat here acquired by the underground waters varied in amount from three to four degrees above the mean temperature of the air for January (seventy-two degrees) to as much as twenty-five. On the other hand, west of this zone in the Punaluu district we find cool perennial springs displaying a constant temperature at the coast all through the year of about 64 degrees; whilst an inland spring at an elevation of 3,000 feet had a temperature of 58.5 degrees. This is the Mauna Loa zone of influence; and we have here then an indication of the independence of the two zones so far as the temperature of the underground waters is concerned."

THE DISPLAY OF 1899.

It was my good fortune to have been in Hawaii in 1899 and to have witnessed from a distance the beautiful columns of liquid lava rising several hundred feet above the surface. I collated the facts observed by myself and others in a *Bulletin of the Geological Society of America, Vol. 12,* and present them essentially as they were printed at that time. Upon the Mauna Kea side of the mountain the principal crater developed at this time is called the "Dewey Crater," after the visit of J. R. Wilson, who planted the United States flag there July 22d, and christened it, as mentioned, in honor of the distinguished Admiral whose exploits were then fresh in mind. There were seven, besides the guide in the party.

On June 20, 1899, a very distinct earthquake shock was felt at

Wailiilii, my temporary residence, twenty-three miles from Hilo, eight from Kilauea, and twenty-four in a right line from the place of outburst. It was at 7:40 P. M., and lasted about a quarter of a minute. At about the same hour two shocks were observed at Hilo, one of them quite severe. None were noticed at the Volcano House by Kilauea, which is eighteen miles from the place of outburst. A few days later another shock was felt; also on July 11, and perhaps later. It is natural to believe that these earthquakes had a direct connection with the eruption, especially as they were particularly manifested along a supposed axial line of lava accumulation.

On the first day of July the manager of the Egan coffee plantation, twenty-one miles from Hilo, saw a light above the top of Mauna Loa, or the pit Mokuaweoweo. On the morning of July 4 this light was quite conspicuous from both Hilo and Punaluu. Early July 5 there came an outburst of liquid lava from a point in the ridge six miles northeasterly from Mokuaweoweo and thirty from Hilo. It was best seen at Kilauea. The people there had been expecting an eruption in their own volcano; hence when early in the morning they heard a great noise like thunder and observed a flash of light they looked to see commotion in Kilauea. In this they were disappointed, and, looking in a contrary direction, saw the beginning of the flow of 1899 from Mauna Loa. Fountains of liquid fire spouted hundreds of feet high, at an elevation of about 11,000 feet above the sea. The place of discharge proved to be near to but higher than the source of the flow of 1880, and not far away from the terminal cones of the discharges of 1823, 1843, 1852, and 1855.

Parties commenced immediately to travel to the source of the flow, contrary to the report sent east by the press that people were fleeing for their lives, abandoning their plantations to the fiery flood. Citations will be made from the accounts given by Professor Edgar Wood,[24] C. W. Baldwin,[25] Professor A. B. Ingalls,[26] and the Honorable W. R. Castle,[27] the dates of their visits having been July 11, 12, 13, and 16, respectively. I had visited the place of the outbreak in 1883, and speak of it in my notes as a region of indescribably rough lava, both "aa" and "pahoehoe," black, yellowish and brown. Our horses were left some distance behind, as the blocks of lava were too large and rough to be comfortably traversed by them. The crater of the Kau part of the

[24] *American Geologist*, Nov., 1899.
[25] *Hawaii's Young People*, Feb., April, and May, 1900.
[26] *Hawaiian Annual* for 1900.
[27] *Hawaiian Gazette*, July 25, 1899.

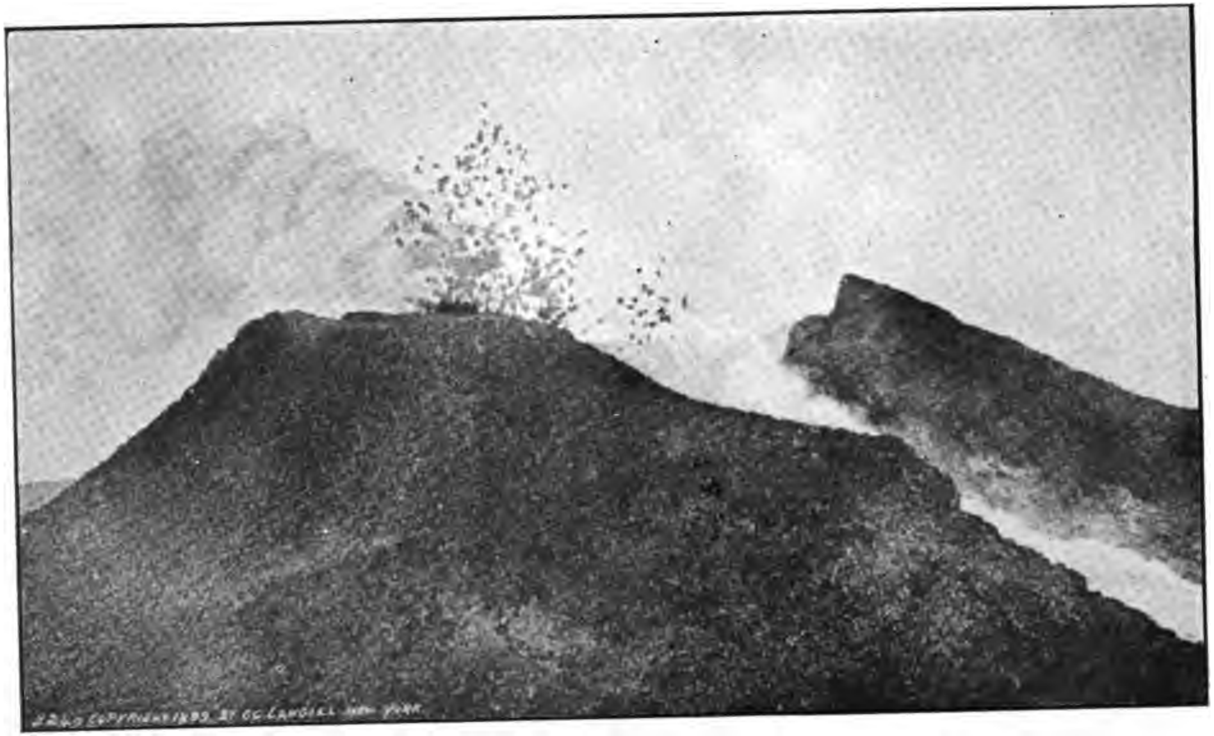
1880 flow was a mass of black and red lapilli. The adjacent terminal crater at the head of the Hilo stream still emitted heat and vapor, more than two years after it started. The 1899 flow began its course near the source of the Hilo stream of 1880, and more than two miles above the beginning of the eruption of 1852. By July 5 two fountains were in operation, at about 11,000 and 10,800 feet elevation, and nearly a mile apart. A week later the upper one had become only a smoky chimney, while a third cone was active near the second. The lava streams from the two openings united and then flowed northerly, directed toward Mauna Kea. Masses of stones and clots of lava were seen to be thrown out with the liquid lava. C. H. Kluegel, chief engineer of the Oahu Railway Company, drew a rough sketch of the cone, with its discharge, estimating the stream to be sixty feet wide, the fall eighty feet in the first four hundred of descent, the velocity forty feet per second, and the depth ten feet. "There is a continuous and somewhat regular flow of lava, with explosions at intervals of one-half to one-eighth second. The lava is thrown up almost continuously one hundred and fifty feet and occasionally two hundred and fifty feet high," says Kluegel. For several days, when the air was free from clouds, the fountains of lava were beautifully exhibited from the Volcano House both day and night. The fountain constantly shifted its position, and when nearest the edge of the cone the falling clots resembled spangles of gold in the night-time. Plate 21 shows the condition of things on July 19, as photographed by C. C. Langill, whose camera was evidently situated on the third cone, the one shown on the left of the principal vent. It proves the ejection of lapilli and vapors from the orifice.

PROFESSOR WOOD'S OBSERVATIONS.

Of the appearances July 11, Professor Wood writes thus:

"There were two principal live cones, one much more active than the other. Great masses of rock at a white heat were being hurled high into the air. These were probably pieces of the crater wall. Sometimes quantities of molten lava were blown out; at other times a mixed material in which there was a great deal of sulphur. This molten matter would sometimes be thrown to the height of two hundred feet. Almost continuously it went higher than one hundred feet. This process was going on with almost no interruption, while at intervals great volumes of smoke poured forth from the edge of the crater. The principal cone was about one hundred and fifty feet high on the north side. The other

PLATE 21.



Cinder Cone (Dewey), 1899.

sides were considerably lower. A deep crack between thirty and forty feet wide ran off in an easterly direction. The cone itself was nearly, if not altogether, two hundred feet across the top, filled with lava at a white heat, never still, ever leaping, sometimes higher, sometimes lower, ever falling back upon itself or spilling in flakes over the side of the cone. Explosions were numerous, almost continuous, while all the time the rushing, roaring sound of the fire fountains filled the air. Wonderful as was this sight, the view of the river of fire was not less so. It rushed through the opening at the speed of a race-horse, and, plunging over a fall of perhaps fifteen or twenty feet, went madly through a deep channel down the side of the mountain. It rushed along with such force that the surface was marked with undulations like the waves of the sea."

C. W. BALDWIN'S OBSERVATIONS.

The visit of the brothers, C. W. and E. D. Baldwin, followed that of Professor Wood, not far from the 12th of July. From a prolonged sketch the following items are gathered: The whole region about the active cone was a tough network of new flows, and they appeared to have gone in every direction. The sounds increased as we came nearer, but they were only such as would come from a violently tossing mass of liquid matter. They did not speak of the explosions that were reported later. The third cone is only a stone's throw from the latest active one. The lava which was thrown into the air went up in a red-hot mass, but turned black as it fell. Pumice was noted among the products of the eruption. There were two or three light earthquake shocks when the flow stopped.

PROFESSOR INGALL'S OBSERVATIONS.

Professor A. B. Ingalls reached the eruptive cones by way of Mokuaweoweo, starting from Kona, on the west side of Hawaii. The route was more difficult than the approach from the Kau side. He found the upper cone to be "merely a smoldering heap, while the lower and farther one was the real fountain-like crater." * * * The upper one "had the shape of a truncated cone, with a deep gash on the upper side, in which we could plainly see hot rock. From this vent, as well as from the top of the cone, great volumes of sulphurous steam poured forth. The trade-wind carried these fumes over the southwest side, compelling us to pass along the north and east of this pile on our way down to the spouting crater." On the north there was a deep layer of sponge-

like pumice, which impeded progress, like deep sand. The lava had flowed down as "aa," and the same clinker material filled the region between the cones. "The display was a continuous lava fountain without cessation. Rocks were ever rising from or falling back into the mighty cauldron, and yet the shapes of the pieces and the general structure and outline of the masses as they stood for an instant before commencing to fall back into the seething pit was never twice alike; so with the clouds of vapor." At one time it was a dome pinnacled by a column of flame; at another, an Eiffel tower stood in outline for an instant and then fell back in a heap of ruins.

On the return Professor Ingalls and his party were in danger of being enveloped in and strangled by the sulphurous fumes.

STATEMENTS BY W. R. CASTLE.

The estimates given by the Honorable W. R. Castle agree with those already quoted. At night an occasional heavy thud gave evidence of the proximity of a live volcano. He says:

"The cone is probably two hundred and fifty or three hundred feet across the top, and is filled with a restless, surging mass of white-hot lava, always leaping into the air, sometimes rising to a height of two hundred feet. Explosions are continuous. Now and then a heavy volume of white smoke is literally shot into the air. It is always rising and rolling away, covering the island with a thin, vapor-like pall." * * * "In two seconds an acre of ground would be covered a foot deep with lava." * * * "Stalactites formed before the rush wholly dropped, and in a moment they could be seen hanging from the roof, still dripping, but all bent downstream."

THE VENTS AND FISSURES SITUATED UPON A WATER-SHED.

The 1899 and older flows started from near the crest of a ridge or watershed and extend from the summit northeasterly, including Puu Ulaula and Kulani. The points of eruption are so near the crest that a slight change in its position would cause the lava to flow toward the north (Kea) or toward the south (Kau). The 1899 flow was thought at one time to be moving south, but it finally discharged north. In this respect it recalled the fact that the flow of 1880 had moved in three directions.

The 1899 flow continued to run till July 26, having a length of fifteen miles and a width of about a mile along its lower course. It consisted chiefly of "aa."

Extensive fissures follow the crest of the ridge, from one or

more of which the latest discharges have proceeded. Some of them may be followed for miles, both up and down, but none have been reported immediately adjacent to Mokuaweoweo. Corresponding crevices have been described as pointing toward the summit at Waiohinu, Kahuku, Kealakekua, and other localities, so that we have the phenomenon of a central elevated pit with immense fissures directed radially from it, and all the eruptions known are located on some one of these fissures.

ATMOSPHERIC PHENOMENA.

A column of smoke constantly arose from the points of ejection, visible on all sides. It expanded as it arose, and closely resembled the so-called "pine tree" shown on photographs of eruptions from Vesuvius. The northeast trade-wind does not reach the altitude of the outbursts; hence the vapors may arise vertically and be spread out on all sides like an enormous umbrella. While the south wind blew, the smoke cloud reached Honolulu, two hundred miles distant. Some people observed a distinctly sulphurous odor, while one gentleman asserts that he had been clearly struck in the face by particles of the volcanic dust. July 17 the steamer "Mariposa" observed this smoke, some six hundred miles to the northeast. Similarly the officers of the "Morning Star" found themselves unable to take the customary observations for latitude at an equally great distance to the southwest. The diameter of the area obscured must have considerably exceeded 1,200 miles, as the observations reported were much to the north of the major axis.

It was also interesting to observe the presence of an enormous cumulus cloud directly over the crater of Mokuaweoweo. This was developed by the rising of heated vapors from the summit crater coming in contact with a cooler atmosphere; and was observed by myself July 14 and 15 from Kau.

Of other notices of similar clouds is that by a member of the Challenger expedition in 1875, which see, *ante;* and by W. L. Green in 1881, over a flat to the west of Hilo where the lava had got dammed up in its course. In the daytime a waterspout is seen descending from the cloud, while the lower end is being driven off in steam by contact with the hot rocks. By night the cloud has a blood-red color. Mr. Green ascribed the phenomena to the indraught of moisture-laden air towards the heated area—the vapors being condensed when they arrive over a cooler stratum.

Analogous appearances have been seen in connection with fires,

as in the case of the Chelsea, Mass., conflagration of April 12, 1908. A. L. Rotch says the air was rather dry that day so that the formation of the cumulus clouds some few miles high was not so easy. B. M. Varney says these cumuli were imperfectly formed, and they did not appear directly over the fire, but a considerable distance to the leeward. In December, 1896, clouds were more perfectly formed over the burning of a coal pocket belonging to the Boston and Maine Railroad Company.—Science, May 15, 1908.

Concerning the appearances in Mokuaweoweo July 13, Professor Ingalls writes:

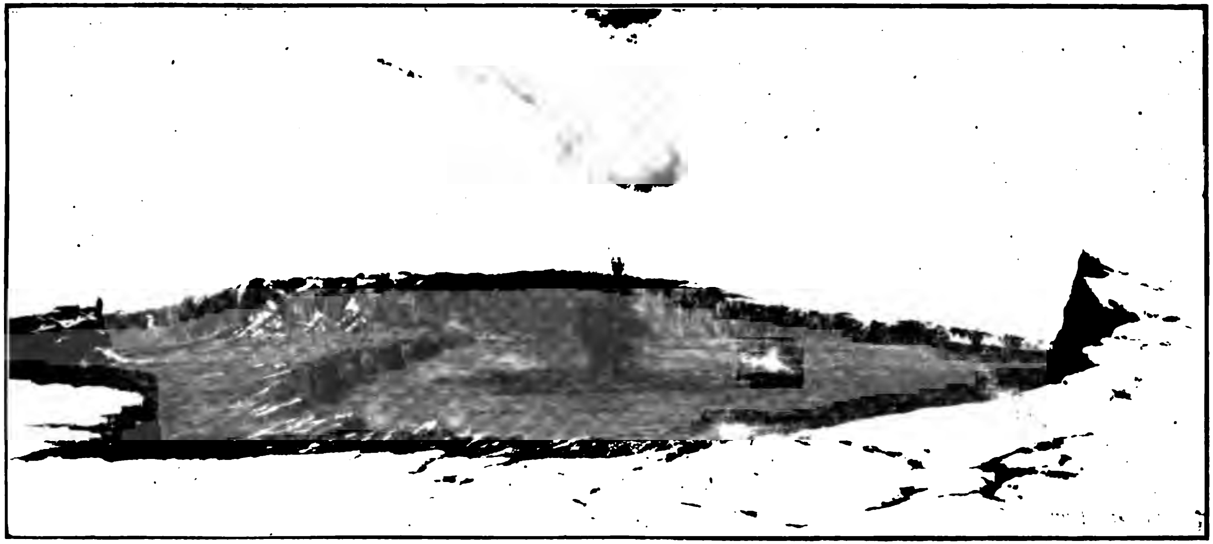
"The floor of the crater was of black lava, to all appearance precisely like that of Kilauea, with a few rough patches here and there which I believe was 'aa.' Extending in a direction roughly parallel with the west wall, from the talus at the base of the lower terrace at the north pretty nearly to the gap in the south, there stretched a crack in the crater floor, all points of which lay slightly west of the medial north-and-south axis. From various places along this fissure rose up nearly all the signs of the existence of the volcanic fires beneath, these evidences being sickly jets of steam, rising in such a manner as to suggest no urgency from below; also at the bottom of the southwest wall the talus appears to be undergoing a transformation into sulphur banks. There was nothing in the appearance of this summit crater to warrant an assumption that at this very time, at the depth of 3,000 to 3,500 feet below the level of this flood, there was a genuine volcano in terrific eruption." [28]

MOKUAWEOWEO IN 1903.

Professor Edgar Wood gave a brief account of a display from the summit in October. On Monday the 5th instant the British ship Ormsery noticed a boiling of the sea off the Kona coast of Hawaii. The temperature rose and the ship received a shock as if from a tidal wave. October 6th a column of smoke was observed rising from Mokuaweoweo—said to be two miles high and three-fourths of a mile wide. Soon there seemed to be a stream of lava flowing down the Kona side of the mountain.

Surveyors Baldwin and Dodge reported what seemed to be a flow on the west side of the mountain towards Kahuku. "The smoke from the summit rose in three columns, two small and one large. The columns were aligned almost due east and west. The larger column was on the east towards Hamakua. The columns as they rose, united to form one great column that rose to a great

[28] Hawaiian Annual for 1900.



Mokuaweoweo in 1903.

height, and in some cases spread out like a great umbrella, the under part reflecting the dull glow of the fires beneath. * * * The lava in the crater showed along a line running through the crater northwest to southeast. There were three principal fire-fountains from which the lava flowed over the crater floor." Steam issued from a multitude of points over the whole floor, It is said that the floor rose three hundred feet and then settled back again. The last glow was seen December 7th at 10 P. M.—*American Geologist,* Vol. 34, 1904.

In the record book of the Volcano House under the date of October 13th, T. C. Ridgeway has given rough sketches of the appearances in the floor of the caldera corresponding to the statements above. The lake was said to be half a mile in diameter, and the number of fire-fountains from twenty-five to thirty, playing to the height of five hundred feet. The flow extended for two miles upon the northwestern part of the floor of the crater. Plate 22 represents this eruption.

The editor of the *Hilo Tribune* reported the following conditions upon Wednesday, October 21st: There was a large fountain in the center hurling to great heights much molten lava and hot boulders: smaller masses were accumulating upon both sides. In the night the large central cone exploded and fell to pieces, and was replaced the next day by a dozen lively geysers. A new pyramid was built up from them, from which there emanated sprays of fire, compared to a group of sportive mermaids from an ocean. Their lithe, bright forms bowed and bent themselves, and disappeared in the darkness only to be followed by dozens and scores of other fairies who kept up the fire dance all night." The scene was also compared to a cathedral of many spires; soon replaced by a single lofty spire, which would fade in its turn and be replaced by others.

Upon November 24th the sea was disturbed at Punaluu, unaccountable waves rising suddenly where it had been smooth before and lasting for ten minutes. At the same moment a black column of unusual size arose from Mokuaweoweo.

December 31, M. A. Hauschild reported that the only signs of activity were a few clouds of steam rising from the eastern and southern parts of the caldera.

MOKUAWEOWEO IN 1905.

Prof. Willis T. Pope, of Honolulu, has kindly favored us with a brief sketch of his ascent of Mauna Loa in 1905. The route was different from that essayed by any of the earlier explorers, and for some reasons it is preferable to the others.

Our party for the trip to Mokuaweoweo on Mauna Loa consisted of three persons: Joseph Gaspar, the guide, Mr. R. O. Reiner, and myself. We started from Napoopoo on the west coast of Hawaii at about 6:30 A. M., July 16th. Each rode a mule, and our supplies for the trip were carried on a pack mule.

From our starting point little could be seen of Mauna Loa on account of the timber and great mass of clouds that floated above its summit. The trail led up a constant incline through the guava bushes. Soon it entered a region covered with a dense growth of koa and ohia forest. The soil was rich and dark in color, and showed but little evidence of having been a lava flow; however, we could occasionally distinguish where the flows of aa had been by the more dense growth of plant life. About eleven o'clock we reached the Greenwell dairy, a ranch house where our ten gallon water tank was filled. From this point the woods seemed to grow more scanty and the koa trees less numerous. About 2 P. M. we halted near a clump of trees and made our camp. This was the highest point where we could find good grass for the mules. The elevation is about 7,000 feet. There was no wind and the woods were silent, very few birds were to be seen or heard. The wild hogs that are said to be so numerous kept out of sight, but there was evidence of their having rooted in the patches of soil before we appeared. The night was cool and the thermometer registered 43° in the early morning. By 6 A. M. we were again packed and off. The trail soon entered upon the naked lava where we could get a good view of the entire western slope of Mauna Loa and also a grand view of Hualalai. The entire mountain side is composed of a vast field of pahoehoe separated by great flows of aa. Here the lava is grayish black in color and much broken up due to weathering. There are no indications whatever of gulches, but occasionally there are great caverns large enough to ride into on horseback. The flows of aa become so numerous that it is difficult to find a way around the various peninsulas of it. On one of these large rivers of aa there are nine different cones or blowholes that are from fifty to one hundred feet across and of about the same height. In many places the lava has flown down in narrow streams looking like plantation ditches. The mules would often follow in these ditches for several hundred yards until it was necessary to get out on account of the stirrups striking the sides, or the mules breaking through into cavities below. The aa became much more numerous as we approached the summit, and the last mile or more was made through a flow of it. All of these upper flows appear as fresh as if they had just been formed. From this Kona side the angle is about the same until the top is reached

and we came upon the edge of the top crater rather unexpectedly to me.

We arrived at the edge of Mokuaweoweo at 2:20 P. M., having made the trip in a little over sixteen hours, counting out the night spent at the timber line. We were now near the highest point on the west side, 13,675 feet, and made our camp in less than a hundred feet of the edge. All along the edge there were many huge cracks varying in width and depth. In one place a crack is over a hundred feet in width. Many of the narrow cracks contain great masses of ice some twenty or thirty feet below the surface which has formed from the snow that fills them during the winter months. The noon-day sun melts little pools in the tops of these ice masses and from these we got good drinking water.

After a hearty dinner we walked along the edge toward the south end of the crater. The great walls are quite vertical, highly colored and in general appear much more grand than the walls of Kilauea. Along this side it is supposed to be from 500 to 1,000 feet to the bottom inside. There was smoke and steam arising from many cracks in the crater and near the south end there was quite a dense column creeping up the side and gently floating toward the southwest. During our entire stay on Mauna Loa there was no wind. By sundown we were back to our camp—the sunset was not a very grand one—and soon we were wrapped in our blankets. None of us slept well during the cold night: all seemed to have a headache. The thermometer registered 27°.

Next morning we were up early and after an attempt to drink some strong coffee we were off toward the north end of the crater and looking for a place to get down inside, which was found. In order to get down we were compelled to climb among the great boulders that seemed very dangerous. At first the bottom was rather smooth but grew rough as we got nearer the large crater. We went down three different ledges each two hundred or three hundred feet in depth. The floor got rougher as we advanced, great ugly masses of twisted lava were interspersed with cracks and holes, and it had the appearance of having been burned or rather charred too much, and it cracked and crushed as we walked over it. From cracks and blowholes steam and sulphur smoke came out. Near the center is a cone about two hundred feet high. This cone is streaked with sulphur which gives it a very pretty appearance.

We returned by very much the same route as we had gone in. On both trips about the crater we noticed huge boulders, as large as barrels, that had been scattered here and there upon the lava outside the crater. They were of a yellow clay color and some

quite red. Some of these had broken through the lava until they were almost buried, showing that they must have dropped from a great height; and they were entirely unlike the lava into which they had fallen.

Progress was very slow; though we did not rest very long at any place, our pedometer only recorded about a mile per hour. On reaching our camp we packed and started down at once about 11:30 A. M. The journey down was pleasant and we felt better as we advanced. No attempt was made to camp and eat as no one cared for food. We traveled thirty-one hours without food. Reached the Greenwell ranch about ten o'clock in a downpour of rain.

NOTES UPON THE KAHUKU LAVA-FLOW OF 1907.

By S. E. Bishop.

The earliest intimation of this great eruption was immediately after midnight, opening January 10th, when a powerful glare was observed at Hilo, over the caldera of Mokuaweoweo, on the summit of Mauna Loa, forty miles distant. This evidently proceeded from a copious emission of lava upon the floor of the crater.

That glare appears to have abated after about three hours, perhaps obscured by smoke, but more probably owing to the transference of activity to the Kahuku district. There, about 4 A. M. on the 10th, burst forth enormous fountains of lava, flowing rapidly down the mountain slope. The precise location of this eruptive source has not been accurately located. It has, however, been visited. It is believed to be about 8,500 feet above the sea and nearly half way from Puu o Keokeo to the summit of Mauna Loa. Keokeo is a prominent cone on the top of the great Kahuku shoulder of Mauna Loa, altitude 6,300 feet and twenty miles S.S.W. from Mokuaweoweo. The flow of 1887 broke out a short distance below Keokeo. This new flow starts eight or nine miles above Keokeo.

Its source seems to be on the slight ridge stretching up from Keokeo, from which the land falls off on either side. Several small branches were observed to the east and west. The main flow at first took a route east of Keokeo, soon invading the area occupied by the flow of 1887. It seems to have crossed the upper part of the latter, continuing to occupy the west border thereof until below the Government road seven miles from the sea, crossing the road early on the 13th.

PLATE 23.

End of Lava Flow of 1907.

The bulk of the flow appears about that time to have been diverted to the west side of Keokeo, forming what is called the Manuka flow from the name of the district invaded by it. It came down with great rapidity and force, crossing the road during the night of the 14th. There were some two hundred white observers, gathered from the northern and western parts of the island.

This division of force prevented either branch of the flow from reaching the sea, as did the eruptions of '68 and '87. They stopped three or four miles short of the shore, but while still in motion were observed on their fronts by some two hundred and fifty passengers from Honolulu, who went up on steamers, landing immediately below. The general map of Hawaii, Plate 14, shows the course of this flow, and Plate 23 its end.

NATURE'S PYROTECHNICS.

By Dr. A. S. Baker.

As we sat at breakfast at Kamuela on Thursday morning, January 10th, 1907, the Chinese cook remarked, "Plenty fire on Mauna Loa last night." True enough, as several servants reported, though but few others at Kamuela saw it. * * * On Saturday night at our home in Kona the glow was bright but well down on the side of Mauna Loa. The flow had evidently proceeded underground and broken out afresh at an elevation of perhaps 7,000 or 8,000 feet near Puu Ohohia. From this later opening has poured the fiery flood which in two streams has buried the Government road, destroyed the telephone line, and it is reported, has again united below, spreading over the flatter country some little way above the ocean.

Earthquakes have been slight and few in number in Kona, though many little ones were reported in Kau. The earthquakes began just a little before the outbreak, and the last one observed by me occurred on Sunday, January 29.[29] Since then the flow has been dying, and after two weeks from the beginning the flow is reported over, and our energetic Telephone Company has managed to string its wires across the Manuka flow, ready to open communication again with Kau.

Sometime during the night of Saturday, January 12th, the first stream crossed the road, at an elevation of perhaps 1,800 feet

[29] Another authority says "the eruption was preceded by earthquakes of unusual character which continued at intervals till the 11th, seven being felt at Kau on the closing date."—Thrum.

above the sea, for on Sunday morning no telephone message could be sent over the telephone line to Kau. Early Monday we started for the scene, some thirty-six miles from home and about five miles south of the Kona line. A few had visited this flow on Sunday night, but Monday was the greatest day of all—both for magnificence and variety of display and for the crowd present, which I estimated at about one hundred and fifty. All kinds of vehicles were seen in use, from an automobile to an old family brake driven tandem, with one boy perched on the forward horse. The stream of people poured in until midnight.

We arrived just at dark and prepared to camp under the open sky a fourth of a mile from the flow, on a little rise beside the tent of Mr. Aungst, who had remained over in charge of the telephone. Every one could enjoy this most awe-inspiring sight, although it was a quiet enjoyment as far as noise went. The flow was also quiet, for but little sound could be heard beyond the constant clink of falling stones as the front wall of solid fire advanced, or an occasional rushing sound from the central molten stream, or a faint explosion of gas. We could enjoy it because we were all in comparative safety and the flow was doing very little damage because of its position on still older flows.

Once before I have felt something of the same awe, and that was on beholding the results of the wearing force of water, as viewed from the brink of that stupendous canyon of the Colorado River in Arizona, which is over a mile deep and hundreds of miles long. Here in Mauna Loa we have the absolutely irresistible force of fire, and one felt it overwhelmingly as he watched it advance straight towards him. As I stood but a few feet in front of the slowly advancing snout of this writhing fiery monster, I could only say to myself, "What is man, that thou art mindful of of him?" and feel with Micah, "Behold, Jehovah cometh forth out of his place, and will come down, and tread upon the high places of the earth. And the mountains shall be melted under him, and the valleys shall be cleft, as was before the fire, as waters that are poured down a steep place." And to remember that the other side of this same mountain summit is covered with glistening snow!

We had hoped to reach the first flow which had crossed the road already, but a glance at the one now advancing showed us how fool-hardy would be such an attempt. The first flow was in Kahuku, in the flow of 1887 and overlapping it toward Kona. This was reported to have flowed almost molten and very rapidly, and it was said to be from a half to a mile or more wide. Our flow was about six miles this way on the Manuka lands. At 5:30

P. M. when we arrived, it was perhaps a half mile above the road, but by midnight it was far below. It crossed the road about 9 P. M., covering the road where we stood so shortly before to a depth of twenty-five feet and more with its glowing rocks. The very front part was an almost perpendicular wall about fifteen feet high, for it did not quite reach the top of the eighteen foot telephone poles, which were soon in a blaze as the wires parted.

We could see this flow for some ten or fifteen miles from the opening, marked by the red changing glow on the clouds of sulphurous vapor and smoke. It was probably some two-thirds of a mile wide, and showed us all kinds of phenomena. Its movement varied greatly, for though advancing with scarcely perceptible motion for some time, it later crossed the road with a sudden rush and hastened below. This movement was not at all dependent upon the slope of the ground, but on the varying amount of material conveyed from the source. A friend called my attention to the glacier-like resemblance of the fiery front and edges with its cooler blackened top constantly falling over as it advanced. After this mass of seething aa passed, the center seemed to run a molten stream carrying down huge masses of all shapes and sizes, red-hot or cooling in all stages. At times every one was reminded of a stately procession of massive ships, or again of a river at flood bearing away houses and people. Above us appeared rapids where the waves of fire tumbled and broke into fiery spray, and again there was a hill which formed a breastwork at one side behind which the flood gathered until a more copious flow overtopped it to spread a solid sheet of flame in a huge semi-circle to its base. Again and again through the night this would cool, and again and again overflow. The whole surface of the stream was constantly changing, black or fiery, at places resembling nothing so much as the lights of an enormous city, especially that portion below us. The scattered trees burned here and there in its course, and the whole region for miles about was turned from night almost into day. For the first few days, until smoke filled all the air, I could tell time on these moonless nights when in my room over thirty miles away. Little fiery explosions arose here and there on the flood, and occasional short side flows appeared. The heat was intense on nearing the flow and a fine cindery dust parched the air, but we were fortunate in having a strong breeze to drive off the smoke from our side, although occasional hot eddies were whirled about us. Heat radiations kept all the air aquiver, and for sometime after our return home our eyes felt badly, and every light quivered and twinkled.

The scene by daylight was nothing compared to the scene by

night. Fire scarcely showed at all, and one could almost step upon the flow without knowing it, were it not for the still quavering radiations of heat. The clink of falling stones was still heard from the sides, but the appearance was only of a huge ridge blackened by a fire which had passed, although the trees were still burning in the distance.—From *The Friend,* February, 1907.

The lava at the original place of emission had cooled before the second flow commenced; but there was a continuous line of vapors along the line (fault) between the two openings. At the upper outlet the material was pahoehoe changing to aa lower down. The same was true of the lava from the second outlet, which was aa at the crossing of the Government road from fifteen to thirty feet thick. At the lower end it had become over fifty feet thick.

The party were able to look down from near Keokeo into a lake of red hot lava eight hundred feet in diameter, and saw two holes in the bluff out of which the stream was issuing. Near the sea shore there was a fountain fifty to sixty feet high. The flow ceased January 24.

Hon. G. C. Hewitt viewed the spectacle from the Kau side on the last night of its activity. A large lake, half a mile long accumulated from the stream, but was not permanent. "Shortly after forming there began to arise upon the surface many vivid flashes, tree-shaped, but fluttering rapidly and becoming so numerous as to finally merge into one broad sheet of flame. These flashes were of the most vivid colors of the rainbow, and continued from one end to the other." * * * "Meanwhile, apparently about a mile away and slightly lower in elevation, in a deep gulch, a hill began to form, growing rapidly and becoming as it grew of a dull reddish form. This hill increased to an immense size and widened till it was as large as Diamond Head." Later the hill began to crumble and the whole mass flattened out down the side of the mountain, covering a territory a mile wide with aa. There were other masses of aa spreading over the mountain side.

Simultaneously with the cessation of this flow near Kahuku Kilauea renewed her activity, said to exceed any of her wakeful periods since 1894. Halemaumau filled up very noticeably.

Sept. 10, 1907. The following is from the record book of the Volcano House. At 6:45 A. M., a very black cloud over the top of Mauna Loa, with flashes of lightning. At 7:45 the cloud began to disappear, spreading out into a fan and growing thinner. 8:30—Cloud all gone. People at the Mahogany Lumber Company's mill saw three large columns of flame through this cloud. Sept. 11, 4 A. M.—From this mill a pronounced flow was seen on the other side of Red Hill.

PLATE 32.

Lava Adhering to Trees, 1868.

FOSSIL TREES IN LAVA.

In the definition of fossils it is expressly stated that the impressions made by organisms upon other substances must be included as well as where portions of the animated object had been preserved. Thus a footmark proves the former existence of an animal as truly as a bone. In Hawaii we have the impressions made by the stumps of trees upon the encircling lava, where the heated streams flowed through a forest. One would think that the trees would be entirely destroyed, but as a forest fire leaves behind the stubs of trees unconsumed and standing like sentinels, so the lava streams have been unable to burn the green wood of the interior. The simplest case is where a stream has pushed its way rapidly through the trees. All the brushwood, branches, bark and leaves are consumed, but the heart of the tree refuses to yield, and the trunks are coated with lava. In other cases the branches have caught bits of lava that have been sprayed upon them. Such an example is illustrated in Plate 32 where the lava has adhered to the trees twenty feet above ground. This was in the 1868 eruption at Kilauea iki and these evidences of the flow were visible there for more than twenty years.

The next stage is where the lava has completely enveloped the trees and solidified around the trunks. In the case of the material falling as ashes the stumps will be enclosed in a similar manner and be better preserved, as seen at Moanalua, on Oahu, by the side of the railroad (Plate 6, Fig. 2, Geology of Oahu). These were compared with the casts of Carboniferous trees found at the Joggins in Nova Scotia, which were surrounded by thick strata of sand. After the decay of the trees deep holes took their places into which amphibians fell and were entombed by a later deposit of sand, and the trunks were replaced by solid sandstone. Usually after the decay of the trees only cylindrical holes are left, upon whose walls may be seen the imprint of charcoal and occasionally some of the charred wood. Rarely new forms or other plants take root and grow up in these holes. In traversing the country away from any trail one needs to take care to avoid these holes for fear of accidents.

Near Kilauea, on the Shipman ranch, is a large koa grove in which these tree moulds are abundant, some of them five and six feet in diameter. Smaller ones may represent the locations of so many coconut trees. The lava encircling the ancient trees probably came from Kilauea, and may be twenty feet thick.

In the district of Puna may be seen hundreds of lava tree stumps standing erect in the fields as pillars, often fifteen feet

high. It cannot be said that these pillars originated from the filling up of the moulds, and then the lava removed or that they represent basalt encircling stumps. A better theory is that of Mr. Rufus Lyman, as stated by Rev. Mr. Westervelt. The lava moves among the trees encircling them to its full thickness. Many will burn but the larger ones will chill the lava so that it hardens around them, drying the outer rim. This will then burn, leaving a small space around the tree, which will receive the still plastic lava forced by the pressure of the liquid and make a sheath around the stub. More burning and more pressure will add to the thickness of this sheath, so long as the conditions suitable for the growth prevail. Sometimes two or three stumps are connected by the lava growth. Plate 25 shows one of these tree moulds, much expanded at the top and supporting vegetation.

The Hawaiian legends relate that these tree stumps represented chiefs in the early days, who had been beguiled by Pele to race with her upon the holua sleds, like the contest described earlier of Kahawali. Pele became indignant when worsted in the race and poured forth floods of lava to overwhelm her opponents. Those who were caught were left standing as pillars all over the plain—and many of the people were destroyed at the same time. Kamapuaa, Kamukahi and Papalauwahi were chiefs who were turned into tree-stumps: and the date of their existence would be the time of a pre-historic eruption from Kilauea.

PUU O KEOKEO.

This mountain is 6,870 feet high, rising considerably above the normal slope of Mauna Loa more than ten miles from the sea. As seen from below it appears like a rival of Mauna Loa. It cannot be far from the fissure of the 1887 flow between Kahuku and Mokuaweoweo. Rev. E. P. Baker traveled along this line and found indications of heat at various points. The yellow ash is wanting about Keokeo, while there is plenty of pumice and lapilli, just as in the Kau desert south of Kilauea.

Dr. S. E. Bishop suggests that this mountain may be an active volcano distinct from all others, and that the eruptions of 1868, 1887 and 1907 came from it. As seen from the sea on the southwest side, Keokeo is a larger mountain than West Maui back of Lahaina and has been piling up from local eruptions like Hualalai. Its chief distinction may have been that it was the seat of an explosive eruption when it threw out an enormous mass of yellow ashes, which covered over one hundred and fifty square miles to the depth of ten feet, besides extending unknown distances over the ocean.

Tree Mould.

A. Relief Map of Mohokea Caldera.

B. Lava flowing into pool of water, 1881.

THE MOHOKEA CALDERA.

Upon the southwest flank of Mauna Loa the evenness of the slope is interrupted by the presence of an irregular pit, as if the rock had been removed by an immense scoop. My attention was first called to it by conversation with Mr. Joseph S. Emerson of the Hawaiian Trigonometrical Survey. He inquired into the reason of the depression, and the association with it of certain hills resembling the "Buttes" of the Cordilleras region of the United States. A paper by him descriptive of the region is entitled *Characteristics of Kau,* published in the *American Journal of Science,* December, 1902. I ventured to call the depression the *Mohokea Caldera* in Volume 14 of the *Bulletin of the Geological Society of America,* and gave a further account of it in the same publication, Volume 17, after a second examination of the ground in 1905.

In place of the map with contours I have constructed a small relief map of the caldera thinking that its features may be more readily appreciated. Plate 24A. First is the general situation back from the harbor of Punaluu towards Mauna Loa. Second, are the elevations called buttes. Third, the valleys running northwesterly between the lines of buttes and the sides of the depression. Fourth, the isolated peaks of Kaumaikeohu to the northeast and Puu Iki on the north rim.

The Mohokea depression is situated in Kau, in the southwestern part of the island of Hawaii, to the north of the harbor of Honuapo, which at present is the end of the sea voyage for those who skirt the leeward side of the great island on the way from Honolulu to Kilauea. There is a line of stages from Honuapo to the volcano, rising gradually for a distance of thirty miles to the altitude of 4,040 fet. Hilea, about four miles from the seaport, is the best point from which to traverse the depression. It is the residence of the head overseer of the sugar plantation, who very kindly accompanied me to the principal points of interest in the caldera. From the house, situated upon lava, the road ascends a steep hill covered by volcanic ashes to about 1,200 feet altitude, and thence another thousand feet to Makanao, where the soil seems to have originated from rock decomposition. This hill is on the southeast side of Kaiholena, the highest elevation in the district.

Mauna Loa is an elongated dome 13,650 feet in height, sloping gradually to the sea or to an intersection with an adjacent volcano. On the northwest side, next to Hualalai, the base is 4,500 feet; on the northeast side, next to the extinct Mauna Kea, at the sheep ranch Humuula, the col is 6,600 feet; on the southeast side,

next to Kilauea, the base exceeds 4,000 feet. The slopes to the sea at Hilo and South cape are gradual for distances of thirty miles. The mass of Kilauea is often regarded as being on the flank of Mauna Loa, because there is no marked col between the two. Kialuea is as well defined a caldera, with its own periods of eruption, as Mokuaweoweo. The locations of the eruptions from Kilauea range from Nanawale, in Puna, on the east, to Punaluu on the west, which is on the seashore only three miles from Hilea. A very conspicuous fault extends twenty miles from Kohaualea westerly to near the flow of 1823. The land makai (shoreward) of this fault has dropped down 1,100 feet. A somewhat similar but more irregular escarpment may be traced from near Kapapala to Waiohinu, eighteen miles in length, but is on the south slope of the mass of Mauna Loa. The caldera of Mohokea has this escarpment for its southern boundary. It is an elliptical depression, six miles long northwest and southeast, and five miles wide northeast and southwest, but truncated by the escarpment named. It has been hollowed out from the basaltic sheets of Mauna Loa. The total area is about thirty square miles.

Mohokea differs from the other calderas in three respects:

1. It is not inclosed on all sides, so as to be properly a pit. It is open on the makai side.

2. There have been several flows of lava from it on the open side. (a) From the broadest part, between Puu Enuhe and Makanao. It is of aa, and has flowed down to the sea between Punaluu and an older similar stream toward Honuapu. It is evidently comparatively recent, though not recognizable in the legends of the oldest inhabitant. It can not have been active less than two centuries ago. (b) A small aa flow starts from the cliff on the west side of the gulch flanking Makanao on the west. It does not reach quite to the stage road at Hilea. It is very olivinitic and has issued from under the later pahoehoe which overlies the yellow ash in the immediate neighborhood (c) Another aa stream, still farther west, is about one mile wide where it crosses the road. It issued from the cliff on the west side of Makanao, but from between two spurs of the older pahoehoe. Following this the road traverses a mile of pahoehoe before coming to (d), the last aa flow, one and a half miles wide, reaching to a short distance east of the sugar mill at Honuapo. The older aa streams are covered by large kukui trees (*Cordia*), with their characteristic lighter yellow green color, rendering them conspicuous.

3. The greatest peculiarity in Mohokea consists in the presence of two parallel lines of faulted blocks running northwest

from the southeastern edge. The one on the east is known as Puu Enuhe, rising precipitously along the edge of the cliff to the height of 2,327 feet. This is the most conspicuous of all the blocks and is the one most like the buttes of the Rocky Mountain region. The ridge behind the outer block falls away gradually for nearly three miles, and then rises again abruptly to Kulua, only to fall away again as at first, and reaches nearly to the innermost wall of the caldera. Viewed from a distance on either flank, the ridge resembles a huge worm with a great head and a swelling near the caudal extremity. This resemblance caught the attention of the early Hawaiians, who recite an interesting legend respecting its origin.[80]

To the west of Puu Enuhe lies a valley one and a half miles wide. It is inhabited by Hawaiians who exhibit characteristic features of the life of the olden time. They are highlanders as contrasted with lowlanders. On the west side the valley is flanked by stupendous blocks, of which the first is Makanao, estimated to exceed 3,500 feet in height. It is hardly separated from Pakua, as delineated upon the Government map of Hawaii, 1901. A broader notch separates Pakua from Kaiholena, 3,824 feet high. There are five blocks in this row, into the last of which a tunnel has been driven two hundred feet in quest of water for irrigation. The east side of this line of blocks is quite precipitous, representing the place of a fault. Both the lines of blocks have been elevated, as indicated in the figure, their altitudes being greater than that of the adjacent territory. The lowland between the elevated blocks and the east side rises gradually to the steep wall behind, toward Puu iki. The land is not cultivated for most of the distance, and is covered by the original forest of tree-ferns, ohias, and other hardwood trees, similar to those seen on the Volcano Road in Olaa. On the west side of Pakua may be seen the bed of a mountain torrent, usually dry, but often too full of water to be safely forded. This skirts the eastern border of another lowland area like those already mentioned, save that it is cultivated and used for pasturage. It is over a mile wide and has a floor of fresh looking pahoehoe, sloping gradually to the

[80] Very long ago there lived here a charming maiden with three brothers. Among her visitors was one possessing great attractions, who always came after dark and left before daylight. The brothers found that their sister loved this visitor, and they had suspicions that he was more than mortal. In order to satisfy themselves, they seized hold of him just as he was leaving, and compelled him to remain with them. As soon as daylight came he was changed into this enormous worm. He was evidently one of those deities who could not retain the human form in the presence of mortals after daylight.

edge of the frontal escarpment, about 1,200 feet high. Eruptions of aa have proceeded from this edge along the whole width of the caldera.

The Enuhe and Kaiholena ridges are higher than the slopes of the Mauna Loa basalt opposite them, of which it is supposed they once formed a part. Hence the lowland depressions can not be regarded as the results of canyon erosion; they probably were depressed, while the blocks were elevated. Following the definition of the caldera, it may be said that portions of the mountain crust were dropped, while other sections were elevated. Its development was arrested. The making of the caldera was incomplete. Possibly the great size of Mohokea, comprising thirty square miles, while Haleakala is only nineteen, may have militated against the thorough fusing of the entire bulk.

If these blocks had been left stilted upon their ends, they would be analogous to the obelisk of Mount Pelée in Martinique. Perhaps they had a similar origin.

MOHOKEA COMPARED WITH HALEAKALA.

For a further understanding of a caldera, reference should be made to Haleakala on Maui. This pit has an area of nineteen square miles and the shape of an elbow ,and its principal features have been described in Part I.

The similarity between the Mohokea and Haleakala calderas consists in the presence of steep escarpments at the lower edges of the floor, and both are unlike the typical examples (Kilauea), in that they are open on one side, not encircled by a cliff. Haleakala could be conceived of as consisting of two smaller calderas united along the axis of the elbow; or it might be imagined as formed by the splitting of the mountain and a separation of the two parts, the space between being filled by later discharges.

The gaps are each continued in broad valleys to the sea. Koolau merges into the Keanae valley, reaching the sea at the village of that name, nine or ten miles distant. This valley is now crossed transversely by an aqueduct fully 1,200 feet above the sea, carrying water for irrigation purposes to the sugar plantations of central Maui. The Kaupo gap extends to the sea in a similar manner, taking its name from the locality. These two streams of lava are larger than any now known elsewhere in the archipelago. If the lava should accumulate enormously in Kilauea, and one stream flow south to Punaluu and the other break through the barrier to the edge of Puna and thence to the sea, the topography of the caldera and its outflows would be very suggestive of Haleakala.

PHASES IN THE DEVELOPMENT OF HAWAIIAN CALDERAS.

It is easy to speculate on the relations of the several Hawaiian calderas.

At first there is a simple crater discharging lava from the summit of a dome.

Secondly, the lava is not produced in sufficient quantity to flow over the margin; the opening is sealed, and then the outermost crust breaks up. The crust is too vast to be absorbed; blocks of it will be elevated; other sections will be absorbed, and the outer wall on the makai side may give way. There will be discharges on the lower side. This may be the Mohokea stage.

Thirdly, all the segments of the crust fall into the reservoir beneath; vertical walls encircle a pit. This is the stage of Kilauea and Mokuaweoweo.

Fourthly, the caldera with encircling walls is formed, but the lower walls give way. Great rivers of lava flow to the sea. As the fires die down several craters are developed on the principal floor. This is Haleakala.

Fifthly, the eruptions of the smaller craters like Halemaumau multiply and the whole pit is filled. The caldera is smothered, the smaller craters continue to be developed until the internal reservoir is exhausted. This is the Mauna Kea stage.

VOLCANIC ASH OF HAWAII AND ITS SOURCE.

The district of Kau between Puna and Kona is proverbially dusty. The floor is of modern lava, covered over an area of three hundred square miles with a light yellowish dust. Mountain torrents have washed away some of it, revealing basalts just beginning to disintegrate; that which remains is very loose, easily moved by wind or water. In the older days the natives enjoyed jumping from a high bank into the dust, just as they might leap from a bluff into the water. Of course this material is badly cut down by teams along the roads. It is utilized for the growth of sugar cane everywhere that plantations exist on the west side of Kilauea. These soils are free from rocks and are very deep, so that a crowbar or cane may be readily thrust down its whole length, just as would be true of large piles of wood ashes in a dry country. Neither is there anything adhesive in this dust when wet. No part of it adheres to one's shoes when walking over it in time of rain.

These soils suffer badly from drought. Extensive fields will be parched and clouds of dust will be very annoying, even imparting a reddish yellow tint to the sky. When the rain comes

in torrents much damage will be done to the land by the cutting of trenches and the transportation of earth. The dry and wet periods are registered in the varied and irregular length and diameter of the joints of the sugar cane stalks. In the season of drought much pains are taken to prevent the starting of fire in the grass, as it spreads long distances beneath the surface, because the spongy nature of this ash will allow the access of air to support the combustion.

It is often dangerous to traverse the forests above the plantations on horseback, because the animals unexpectedly plunge into unseen deep holes and break their legs. Surveyors find it impracticable to carry supplies to their workmen by direct routes over these soils and necessarily make wide detours.

In traveling from Kilauea southwesterly through Kau this ash first appears in small isolated areas four miles from the volcano, and then increases in amount and importance, and is more noticeable about the "Halfway House." Between this and Pahala certain piles of it, as at the level of 1,800 feet, resemble terraces. It is the material supporting the Pahala sugar plantations. It has been covered at various places in Kau by flows of pahoehoe. An isolated hill of this sort near the tramway a mile or more northeast from Punaluu harbor is conspicuous. As a rule, the lands near the sea level have either lost this ash by rain erosion or it is covered by the later lava flows. Most of the peaks in the Mohokea area are capped by the ash, though it is recognized most abundantly near the southeast margin.

The promontory called Kahuku Point, South Cape, and Ka Lae is likewise covered by this ash, and has attained the thickness of ten feet, separated into two parts by a thin seam of earth. The late eruptions of 1868 and 1887 destroyed the continuity of this deposit between Kahuku and Kona.

Mr. Emerson has discussed the problem of the source of the aerial eruption, and the writer has referred to the same question ni a paper on the volcanic phenomena in Hawaii."

King Umi's road is referred to as giving evidence of the presence of these ashes for three and a half centuries. He occupied a tract of land between Mauna Loa and Hualalai, where some of the edifices constructed by him were figured by Captain Wilkes and are still to be seen. The road ran north and south, parallel to the shore of Kona, seven or eight miles distant, to a natural amphitheater on the southern slope of Puu o Keokeo, where immense crowds of Hawaiians gathered to witness the cock fights. The pens still stand as they were in Umi's day. The road over

[81] Bull. Geol. Soc. Am., Vol. 12, p. 83.

this ash is said to be only two or three feet wide. If a mule traversing this path deviated but a few feet on either side he would sink down to his girth and flounder helplessly. If a shower of pumice or lapilli had fallen since the days of Umi, the road and the pens would have been swept away or covered up. Hence we must regard the ash deposit as the latest formation of the neighborhood, though still several centuries old.

Mr. Emerson's final conclusion is that we must seek for the source of the ash in the district where it abounds. Considering the shape of our supposed caldera, he thinks the ashes must have proceeded from some part of it. This was the "source of the stupendous explosions or series of explosions which has rescued Kau from being a waste of unproductive rock and transformed it to so large an extent into a land of pastures and plantations."

I have already treated of this question in the paper cited, looking to Mokuaweoweo as the probable source of this and other localities of ash on Hawaii. What is conceived to be the same duplex deposit is recognized at Puakala on the south flank of Mauna Kea, at Hilo, all through Olaa, as well as in Kau and Kona. I have also discovered the same deposit on the north side of Mokuaweoweo a dozen miles west of Humuula sheep station, so that now the great crater has been proved to be encircled by this light, fine-grained material. The absence of it about Kilauea, Puu o Keokeo, and on the north slope of Mauna Loa is occasioned by its removal by the later historic discharges of lava. It would not be found near the central vent because the heated air would carry the particles many thousand feet in the air, whence they would descend miles away from their place of origin. The fact that the Mohokea caldera is covered by the ashes is evidence that they came from a distant vent. Had the eruption been in the midst of the depression, we should look for them in an encircling belt, if not upon the southwest side almost exclusively, where they were deflected by the trade winds.

ORDER OF EVENTS IN THE HISTORY OF MOHOKEA.

Several events can be clearly discriminated in the history of the Mohokea caldera.

1. The formation of the cone of Mauna Loa. This is really composite, but may be treated as a unity for convenience. Basalt came from below and flowed over the edge of the primeval crater till the whole dome, seventy-five by fifty-three miles in two diameters and 13,650 feet altitude, had been formed, composed of millions of layers gradually superimposed upon one another. The

altitude must have been even greater, so as to allow for the falling in of the surface to develop the caldera of Mokuaweoweo.

2. After the material ceased to flow over the surface, two styles of eruption commenced or continued to be manifested; those high up, allowing streams of molten lava to flow away quietly, and those starting from comparatively low levels, discharging with violence. The base of the cone was filled by these ruptures of the basaltic sheets and the discharge of streams of melted lava. The irregularities of the southern edge of the cone between Kilauea and Punaluu were produced at this time. Mohokea was the most important of these displays. The three intermontane valleys sank down in the usual style of the breaking of the superior crust from a caldera. Perhaps, because of the great size of the pit, all the fragments could not be absorbed by the inner fiery fluid; two rows of blocks were crowded up, and the work of fracture ceasing, the great masses of rock were elevated and held in position. It is to be noted that the faults are at right angles to those running seaward from the apex of Mauna Loa. This agrees with the theory of W. L. Green, that the discharges of the lava from the interior of the cone always take place at the intersection of the cross-fissures. Very much lava flowed away at this time, including the three valleys mentioned and the crust adjacent as far as to Kapuna.

3. Two great eruptions, separated by a long interval of time, threw out into the atmosphere enormous clouds of ashes. The intermediate period was long enough to allow of the invasion of plants over the sterile area of silt. Because of the occurrence of this ash entirely around the circumference of Mauna Loa, it seems most likely that the vent was at Mokuaweoweo. A gigantic cloud rose above the trade winds and spread out on all sides, while the particles too heavy to be carried great distances fell to the ground. Three recent eruptions of a similar nature are on record—from Krakatoa in 1883, from Tarawera in 1886, and in 1907 at Vesuvius. I have estimated that 2,000 square miles of the island of Hawaii were covered by these ashes. These are preserved, but they must have been strewn much beyond these limits and lost in the sea. Could any one have observed the skies at this time he would have seen repeated the sky glows, the Bishop's rings, and the green sun. This must have been an explosive eruption—a style of discharge denied to Hawaiian volcanoes by the early writers.

4. Several flows of pahoehoe will be described presently overlying the ash, some of them from the Mohokea depression itself.

5. More or less connected with them are several discharges of aa.

6. Last of all, I should not fail to recall the disastrous earthquakes of 1868, whose epicentrum lay in the vicinity of this caldera. No more severe shocks have ever been experienced since the country has been settled by people of European descent. The quakes were observed at Kona, Kahuku, Waiohinu, Kilauea, and Hilo. All were severe, but the greatest devastation was wrought in the vicinity of Mohokea. Can it be that the seat of the seismic disturbances lay beneath Mohokea? The chief discharge of lava was on the flank of Mauna Loa several miles west of Mohokea, and there was another from Kilauea in the opposite direction.

ERUPTIONS OF LAVA FROM THE LOWER LEVELS.

The Mauna Loa flows may be classified by the altitudes at which the discharges take place. First, those from the upper part of the dome, as those of 1843, 1852, 1855, 1880, 1889, and 1899, starting from 9,000 to 11,000 feet above the sea. They are strongly characterized by a hydrostatic connection with the central pit at Mokuaweoweo. The lava comes from the extreme depth under the ocean to the caldera, and after two or three days' stay at the summit it breaks out quietly on the side of the mountain, and may flow to the sea level in the course of several months. The other class, as represented by the flows of 1868, 1887, and 1907, shows first the same supply of lava at the summit, but breaks out low down, 3,000 or 6,000 feet above the sea, with violent earthquakes, those lowest down being the most frightful, and the lava issues tumultuously through long fissures. I can now add quite a number to the list of those that have issued from the lower level. They were prehistoric, so that it is impossible to connect them with manifestations in Mokuaweoweo.

In this class I will include several undefined aa eruptions east of Pahala. The first poses on the Government map as having been erupted in 1823, and is quite near Kilauea. As there represented, I think it is made up of three eruptions. The first, prehistoric, 9,300 feet above the sea, near Puu Ulaula, well shown on E. D. Baldwin's unpublished survey. This probably was of the first class, originating high up. The second part must have been of the kind appearing at the surface low down, starting near the line between the Mauna Loa and Kilauea areas, at an elevation of more than 3,000 feet. A macadamized road now crosses it diagonally for as much as six miles, and it is certainly of prehistoric age. It has moved southwest with very little fall.

The third part originated from Kilauea in 1823, and is probably the only area that came to the surface at that time. It was visited by Rev. Mr. Ellis in 1823 and is described in his journal.

The second mention is that of one or more ancient flows between the Halfway House and Pahala. Some of them cover the yellow ash beds, others are much older, or at least they had their day before the deposit of ash. Some of the recent exposures show a beautifully smooth pahoehoe, which when protected by an earthy covering really recall, by their freshness and smoothness, glaciated surfaces in more northern climes. Mr. Mann, one of the lunas at Hilea, told me he had seen five different lava flows belonging to this later period to the east of Pahala. They have a thickness of twenty-eight feet. This is in the vicinity of the mud flow of 1868.

Thirdly, extensive aa flows, which have originated in the depressed area of Mohokea east of Puu Enuhe.

The fourth eruption is aa from between Puu Enuhe and Makanao.

The fifth eruption is made up of at least three aa flows and the later pahoehoe between Hilea and Honuapo.

In the sixth area there are some undetermined factors. Undoubtedly there were discharges on the Kahuku promontory between Honuapo and the 1868 flow, but we are sure of those of 1868, 1887 and 1907, which have been fully described. Farther north I observed from the steamer half a dozen of these short flows, of very modern aspect, before reaching Cape Honumalo. Here commences the steeper slopes of the Kona district for a distance of sixty miles. Much of the way the 1,000 foot contour is only a mile back from the shore, and it rises nearly as rapidly to 3,000 and 4,000 feet. I observed fresh black lava flows at Hoopaloa, Naupoopoo, and Kailua. It seems clear, therefore, that there have been many eruptions from the lower levels of the Mauna Loa dome on the south and southwest sides. Whether any or all of them had direct connection with Mokuaweoweo, like those of 1868 and 1887, cannot be proved; but their situation warrants a belief in their similarity.

HUALALAI.

This volcano is 8,269 feet in altitude, northwest from Mauna Loa and between the flow of 1859 and the sea. Menzies ascended it in 1793 and figures a large crater at the summit with steep walls inside, with the name *Worroway*. Prof. W. T. Brigham represents a cluster of cinder cones crowning the apex as seen from Mokuaweoweo. Dutton says there are many cinder cones upon

it, hundreds in all, increasing in number and size towards the summit. Interspersed among the cones are chimneys with sharp edges at the mouths of hollow pipes which slope gradually to their bases. As he speaks of the caldera, it is evident that he saw recent lava at the summit and the adjacent volcanic depressions.

Prof. Pickering adds further descriptions and illustrations, some of which are shown later. Upon the summit he saw crater bowls, pits, cinder cones and spiracles with strong resemblances to lunar phenomena. There is a bowl eight hundred feet in diameter and two hundred deep with a sandy bottom. Near by is a row of spiracles, the highest reaching one thousand feet above its base. In their midst is the "bottomless pit," exceeding 1,400 feet by direct measurement.

The last known eruption started from the altitude of 1,800 feet and flowed to the sea in 1801, spreading out very much laterally.

The distance between the extreme points on the shore exceeds the length of the flow. Three other very distinct earlier but prehistoric flows are delineated on the north side of Hualalai, starting from points 3,700 to 6,000 feet above the sea level. The 1801 flow was visited by Kamehameha I, who cut off a lock of his hair and threw it into the stream, with the result that the lava ceased to discharge further.

There are no ravines made by erosion upon the flanks of the mountain except in the foot hills, like Puu Waawaa to the north; these last for that reason being of greater age.

PART III

The History of the Exploration of Kilauea.

Kilauea, sometimes written Kirauea, is better known than Mauna Loa because it is more easily visited and has almost always afforded signs of volcanic activity. The altitude of its north bank at the Volcano House is given at 4,040 feet, and is easily reached by good carriage roads from Hilo on the northeast and the port of Honuapo on the southwest, being midway between these two villages. From Hilo there is also a steam railroad for three-fourths of the way, say twenty-five miles out of thirty-one. The ascent is gradual, at the rate of about one hundred and thirty feet to the mile, so that one does not realize that when standing on the brink of the caldera, he is really on the summit of a lofty mountain.

There seems to exist data for a belief in a very extensive prehistoric flow from near Kilauea upon the Government road for over twenty miles southeasterly. At the higher elevations, from about the twenty-fifth to the thirtieth mile posts upon the Government road, the forest growth is wanting. The same is true of a broad strip of country makai of the trail used by travelers from Hilo to the volcano more than fifteen years ago. This trail, called the "worst road in the world," in my note books of 1883 and 1886, seems to have been located just outside of the forest, that belt which covers most of the country between Hilo and the Volcano. It is a magnificent growth of ohia, tree ferns, vines and other plants, answering to the appellation of *jungle*. The climatal conditions are favorable to its continuity over the whole of the region between the present forest and Puna; and it is our belief that the absence of vegetation is due to a large lava stream reaching from an older Kilauea to the lower limits of Olaa. There is a belt of the original growth between the caldera and the beginning of the scanty vegetation, from which immense trunks of the "Hawaiian mahogany" are now being obtained for commercial purposes.

A recent trip from the ninth mile post out of Hilo on the Volcano road to Pohoiki (Rycroft's) confirmed these conclusions. Near the coast there is a dense growth of the Pandanus or lou-hala. Higher up it is replaced by various shrubs, especially the guava. The flow of 1840 is still conspicuous by the sparse vege-

tation upon it, as sufficient time has not yet elapsed to allow the complete disintegration of the basalt into soil and the consequent growth of trees; bushes appear upon the older lavas adjacent. The greater portion of this road between the flow of 1840 and the ninth mile post is situated upon a barren tract of pahoehoe, if possible more devoid of vegetation than the later stream, because less easily disintegrated. I found two small areas of the original dense forest in the midst of this barren tract. One is a mile in diameter, east of Pahoa postoffice; the other is much smaller, near the eighteenth mile post. Large ohias, tree ferns, ropy vines and various shrubs are as vigorous in these islands as in the upper forest, while the interspaces exhibit chiefly the pahoehoe, barren and devoid of vegetation. They are like the outliers of sandstone isolated in a flat country, and supposed to have once covered the whole region. The natural conclusion here is that the forest originally covered the whole of Puna and that a powerful flow of lava came from the barren tract east of Kilauea, burnt its way through the forest, leaving here and there islands of jungle. The general absence of vegetation would indicate that the date of the outflow is comparatively modern, recent enough to have been witnessed by the Hawaiians, and possibly preserved in legendary form.

The first known reference to this volcano in the writings of Europeans is that given by Vancouver in 1794. Under date of January 11th, he writes: "As we passed the district of Opoona, (on ship board) the weather being very clear and pleasant, we had a most excellent view of Mauna Roa's snowy summit, and the range of lower hills that extend toward the east end of Owyhee. From the tops of these, about the middle of the descending ridge, several columns of smoke were seen to ascend, which Tamaahmaah and the rest of our friends said were occasioned by the subterranean fires that frequently broke out in violent eruptions, causing among the natives such a multiplicity of superstitious notions as to give rise to a religious order of persons, who perform volcanic rites, consisting of various sacrifices of the different productions of the country, for the purpose of appeasing the wrath of the enraged demon."

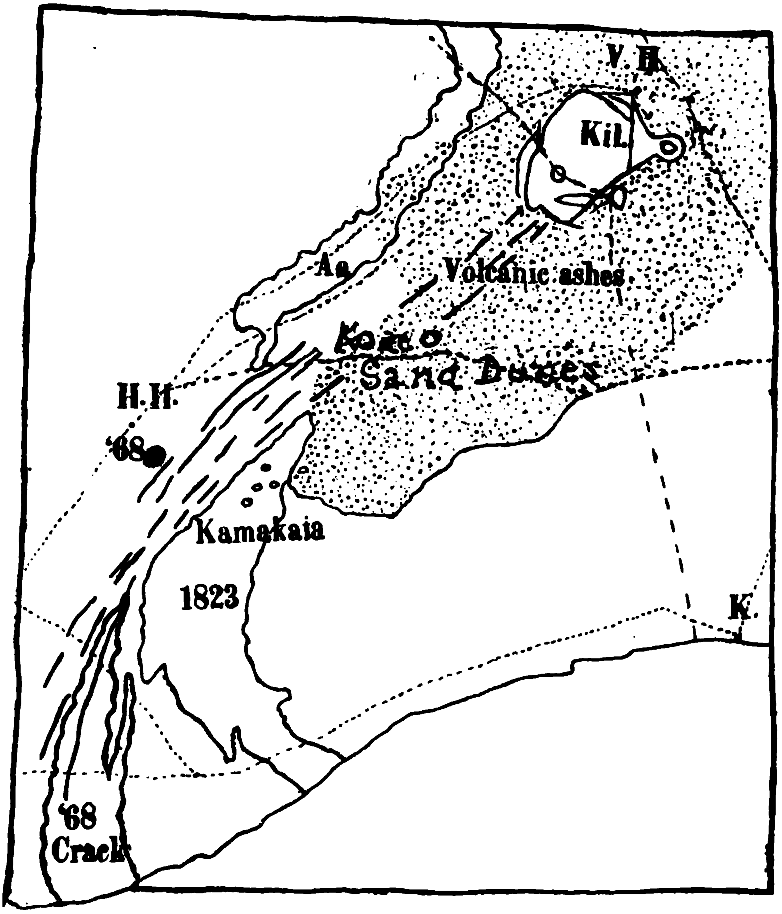
Menzies in his sketch of the ascent of Mauna Loa refers to the "Volcano," from which smoke and ashes proceeded, making the air thick and irritating to the eyes. This was between Punaluu and Kapapala and his experiences were such as have been repeated constantly ever since.

Before citing the account of the next visit to the volcano by an European, it will be well to state what has been learned from the native Hawaiian records, partly historic and partly legendary.

EARLY RECORDS OF ACTIVITY AT KILAUEA.

As is well known, the first detachment of American missionaries arrived in Hawaii in 1820. They gradually made themselves familiar with the island and dicovered the fact of the existence of the volcano of Kilauea. Because the natives possessed no written literature, it has been generally understood that their oral traditions transmitted from generation to generation had no scientific value. Historians have discovered that these traditions are of importance in determining the ancestry of the Hawaiians, and to some extent their chronology; and therefore credence may be given to their statements about volcanic activity. They imagined that the volcano was inhabited by certain deities, and represented that there were struggles among them and that they had the power to produce flows of lava, both superficially and by underground passages from the crater to the ocean. It may be said that these traditions represent the conceptions formed by the natives of the nature of the eruptions; and consequently the deeds performed can be recognized in one or another phase of volcanic activity. Furthermore, the events are said to have taken place during the reigns of particular kings and therefore make known the date of certain definite eruptions. I have not been able to investigate this history thoroughly, but have gleaned a few facts which may be added to by experts.

The first information afforded by the missionaries is contained in a journal of a tour of exploration undertaken in 1823. Rev. William Ellis was an English missionary who had resided for several years in the Society Islands and had acquired a knowledge of the language of that part of the Pacific, which is very much like the Hawaiian tongue. With Rev. Daniel Tyerman and George Bennett, Ellis had explored some of the South Seas. The Hawaiian authorities invited Mr. Ellis, together with two Tahitian chiefs, to reside in Hawaii. The Amercan Board of Commissioners of Foreign Missions took advantage of the opportunity afforded by the presence of these gentlemen to undertake the exploration of the island of Hawaii, primarily for evangelistic purposes, and incidentally for the acquisition of any knowledge of general importance. The missionaries connected with the A. B. C. F. M. who were associated with Mr. Ellis, were Reverends Asa Thurston, Artemas Bishop and Joseph Goodrich, and Mr. Harwood, an intelligent mechanic. All except Mr. Ellis arrived at Kailua, Hawai, June 26, 1823. Before the arrival of Mr. Ellis, eight days later, the company had discovered various signs of volcanic structure, and attempted the ascent of Mauna Hualalai, but failed to reach the summit, for want of supplies.



Distribution of volcanic ashes about Kilauea.

At length the journey around the island was commenced, and numerous references were made to volcanic phenomena, which need not be repeated. They journeyed through Kona and Kau till Kilauea was reached. They noted the conical hills of volcanic ashes not far from Tairitii, near Kahuku, which we now recognize as a part of the deposit blown out from Mokuaweoweo in prehistoric times. After passing the South Cape they began to see the clouds of smoke and to smell the fumes of sulphur emanating from Kilauea. From Kapapala they diverged on a side trip to Ponahohoa, a distance of five miles, where they saw the discharge that came from Kilauea in the month of March. The story was that the goddess of Pele had issued from a subterranean cavern and overflowed the lowlands of Kapapala. The inundation was sudden and violent. One canoe had been burnt and four others carried out to the sea. At Mahuka the deep torrent of lava had transported a huge rock, nearly one hundred feet high, into the water which was still visible. The ground at Ponahohoa[32] exhibited several chasms, some of them ten or twelve feet across, from which smoke and steam was issuing. The vegetation had been scorched, and a considerable heat was still emanating from the recently ejected lava.

This is the only notice we have of the 1823 eruption from Kilauea. In Plate 26 may be seen a sketch of its position and area, party of aa and partly of pahoehoe, occupying a space about fifteen miles square and surrounding the small hills known as Kearaarea. The plan is taken from the recent survey of Kapapala by E. D. Baldwin and George F. Wright, executed under the direction of Walter E. Wall, Government surveyor. These small craters must have been formed long before this eruption, otherwise their names would not have been known. I have never seen any account of them, but they are quite conspicuous as seen from the Kau volcano road.

After reaching Kaimu, several miles east of Kilauea, the deputation listened to accounts of an earthquake which had been experienced about two months earlier. The ground after several minutes of quaking had been rent for several miles in the direction north-by-east, and emitted a quantity of smoke, ashes and luminous vapor, but none of the people were injured. One house was situated directly over the chasm and the people were disturbed in their slumbers. Probably this disturbance was connected with the general eruption of 1823 from Kilauea.

After Kilauea had been visited Mr. Ellis questioned the natives about its history. They represented that it had been burning

[32] Probably near Kearaarea. All knowledge of the older name is lost.

from time immemorial: it often had boiled up and overflowed its banks in the earlier ages, inundating the surrounding country; but for many reigns past it had kept below the level of the surrounding plain, continually extending its surface, increasing its depth, occasionally throwing up large rocks and red-hot stones. These eruptions were always accompanied by dreadful earthquakes, loud claps of thunder and quick succeeding lightning. No great eruption had taken place since the days of Keoua (1790), but many places near the sea had been overflowed; the streams of lava had taken subterranean courses to the shore.

The first incoming of immigrants, as corroborated and dated by the historian Fornander, was in the days of Wakea, A. D. 190, when the volcano was active. The later immigration dates from A. D. 1090; and it was claimed that eruptions had taken place during every reign since that date; which may be estimated as once for every generation. The legend of Pele, detailed later, relates clearly to an eruption from Kilauea, which must have taken place a few years after 1175. About fourteen generations back, in the days of Liloa, 1420, a violent eruption broke out from Keanakakoi. As this seemed to be well known to the natives, it was probably of unusual importance, and is referred to again later. There was also an eruption at Kaimu in the days of Alapai, whose date proves to be from 1730 to 1754, according to Professor W. D. Alexander.

Another tradition relates to the disturbances at Kapoho, a very interesting crater in Puna near the eastern extremity of Hawaii, belonging to Mr. Shipman, who entertained me in 1883, and later to Mr. H. J. Lyman, whom I visited in 1899. Kapoho signifies *the sunken in.* It is the largest of all the craters in Puna, one mile in diameter ,enclosing two hills and a pond of clear water, which is said to be quite saline. Inasmuch as Pele is represented as coming here to engage in the game of *holua,* it seems probable that Kapoho is connected with Kilauea. It was in the reign of Keariikukii ,an ancient king of Hawaii, that Kahavari, a chief from Puna, with others, came to Kapoho to amuse themselves with sliding downhill. Many people came to witness the game, among them Pele. She challenged Kahavari to slide with her, and she was beaten. She asked for his sledge, which he refused to give her. Becoming incensed, she stamped upon the ground, whence followed an earthquake, rending the hill in sunder; and in response to her call liquid fire made its appearance, and pursued Kahavari. He had great difficulty in making his escape down the hill to the sea, whence he was closely followed by fire and stones while his family were overwhelmed. The special site of this action was the crater Kukii, a crater of black and red lapilli half

A. Explosive eruption from Kilauea, 1790.

B. Relief Map of Kilauea in 1823.

a mile northeasterly from Lyman's. The scoriae are pumiceous like that on the south side of Kilauea. The time of Kahavari's domination in Puna is placed by Kalakaua at A. D. 1340 to 1380, in the resign of Kahoukapu.

Another eruption was described by the natives as having been manifested about thirty-five years earlier, say 1788. There are three hills contiguous to each other, to the west of Kapoho, Honualula, Malama (Puulena) and Mariu (Kaliu). These arrested the progress of an immense torrent of lava which inundated the country to the north. This flow must have been analogous to the later discharge from Kilauea in 1840.

One cannot resist the impression that the earlier eruptions were comparable with what are called the Vesuvian or explosive type of action; and Plate 27A is a humble attempt to represent the conditions attending the discharge of vapors, stones and ashes, when the whole adjacent region was covered with the ejectamenta.

ERUPTION OF 1790.

The account of the eruption of 1790 was compiled by Rev. Sheldon Dibble in his *History of the Sandwich Islands,* published at Lahainaluna in 1843. He interviewed several of the survivors of the catastrophe, and was able by repeated questionings to compile a satisfactory account of the events. It was also given by Mr. Ellis in his Journal. Rev. H. R. Hitchcock puts the date of the event at November, 1790, in the chronology of Hawaiian happenings appended to his Dictionary: others had supposed it to be a year earlier.

In the earlier months of 1790 violent battles had been fought between Keoua and Kamehameha in their struggle for the supremacy, and now quite a large detachment of warriors were on the way to Kau under the leadership of Keoua, an immediate descendant of Taraiopu, a chief mentioned in Captain Cook's narrative. He took the route upon the southeast side of Kilauea and was encamped near Keanakakoi. The natives explained the disaster by the friendship of Pele for Kamehameha and hostility to Keoua. Soon after sunset there were repeated earthquakes, the rising of a column of dense black smoke followed by the most brilliant flames, and streams of lava spouted up in fountains and immense rocks were ejected to a great height. A volley of smaller stones thrown with great force followed the larger ones, striking some of the soldiers, and bursting like bomb shells, accompanied by lightning. Many of the people were killed by the falling fragments and others were buried beneath masses of

scoriae and ashes. The natives did not dare to proceed. On the second and third nights there were similar disturbances. Not intimidated by this event Keoua continued his march, separating for safety into three companies. The advance party experienced a severe earthquake and a dense cloud rose out of the crater accompanied by electric discharges. The cloud excluded the light of day, but the darkness became more terrible because of the glare of the red-hot lava below and the flashes of lightning above. Soon afterwards there was a destructive shower, extending for miles around, of sand and cinders. A few persons were burned to death and others were seriously injured. All experienced a suffocating sensation and hastened on as rapidly as possible.

The hindmost company which was nearest to the volcano seemed to suffer the least, and hastened forward after the eruption, congratulating themselves upon their escape. On reaching their comrades of the second company, said to be four hundred in number (Ellis says eighty), they were greatly surprised to find them all dead, although they retained life-like postures. Not one of the party survived, except a lone pig. The suddenness and totality of the destruction reads like the story of the disaster at Martinique, pouring down from Mont Pelée; especially as Dibble adds: "A blast of sulphurous gas, a shower of heated embers, or a volume of heated steam would sufficiently account for this sudden death. Some of the narrators, who saw the corpses, affirm that though in no place deeply burnt, yet they were thoroughly scorched." On their return, after the final battle in Kau, in about ten days time, the bodies were still entire and showed no signs of decay except a hollowness of the eyes. They were never buried, and one of the missionaries is reported to have seen many years afterwards a human skull lying in the volcanic sand. Keoua himself surrendered to Taiana upon the hill of Makanao, one of the buttes in Hilea, described in connection with the caldera of Mohokea.

It has been tacitly assumed that the place where the soldiers were destroyed was near Kilauea. The question arises would not the party have taken the regular road from Puna to Kau. If so, they would have been situated about five miles south from Kilauea. This trail is indicated upon Plate 26 by the dotted line leading from the east border of the map to the sand dunes, close by Koae and thence to the Halfway House. The first part of this trail follows a fault line. It would seem not improbable that the eruption came from some vent now concealed from view, because of the distance from Kilauea; but if all the material indicated upon the map as ashes and tuff came out in 1790, there

could be no doubt as to its calamitous effect upon the army, for there is an enormous deposit of volcanic ashes, pumice, scoriae, lava bombs, stones and rocks spread over several miles between Keanakakoi and the road from Puna to Kau. It must be scores of feet in thickness. Were it removed, who knows how much farther the caldera beneath extends to the south and southwest!

This deposit must have been laid down by an eruption of the most violent type in prehistoric times long before the passage of the troops of Keoua from Hilo to Kau in 1790. It was a truly terrific discharge, fully equal to anything ever sent out from Vesuvius; and this enables us to affirm that Kilauea has sometimes belonged to the explosive class of volcanoes and has not always been the tame creature of today.

Professor J. D. Dana explored the same region in 1887, and was fully persuaded that the material thrown out was connected with the historic event of 1790. "The distribution of the ejected stones, ashes and scoria all around Kilauea seems to show that the whole bottom of the pit was in action; yet the southern, as usual, most intensely so." The heavy compact basalts and their large use indicate that the more deep seated rocks along the conduit of the volcano had been torn off by the violent projectile action. "It was an *explosive* eruption of Kilauea such as has not been known in more recent times."

Professor Dana observed three varieties of volcanic products about Kilauea that seemed to have been ejected explosively from the crater. At the base from twenty to twenty-five feet of yellowish brown tuff including very fine sand well exposed to view near fissures. Above the tuff are two or three feet of coarse conglomerate, including large stones; and on the summit twelve to sixteen inches thickness of a brownish sponge-like scoria, analogous to pumice, in pieces from half an inch across to two or three inches. Less than two per cent. of this scoria is solid: it is a network like thread lace. One solid inch of the basalt glass would make a layer of scoria sixty inches thick. Because of its lightness it will float in water and may be easily carried off by the wind. It is most abundant south and west from the volcano and may be seen near Uwekahuna and at the Volcano House. The stones are about the Volcano House and to the south of the caldera. Towards Keanakakoi the ejected stones of one and two cubic feet are common; others are larger. The largest one seen contained one hundred cubic feet, and must weigh over eight tons. Stones like this are conspicuous from one-eighth to one-half a mile away from Kilauea. Some of them have been observed upon Uwekahuna. They consist of the more solid basalts

of the neighborhood, usually of a gray color and somewhat vesicular. Some carry olivine and all appear to belong to early periods of formation. The tuffs and many stones make up the bulk of the cliffs to the south of the caldera.

The recent (1907) map of Kapapala shows finely the distribution of this eolian deposit to the south and southeast. Not less than twenty square miles have been covered by it; extending for five miles southerly and southwesterly, or as far as to the ancient cone of Koae. There are several volcanic cones such as Kearaarea or Kamakaia in the midst of extensive fissures, both old and new. To the south of Koae are many large sand dunes that have been blown from the ash accumulations.

On the other side of the fissures as one follows the regular road to Kau from Kilauea for nearly four miles, there are numerous patches of fine-grained drab tuff from two or three to six or more inches in extent with scoriaceous pieces and pisolitic spherules which are less conspicuous than the others, but of the same general character and age.

Similar materials may be seen at the saw mill for koa lumber two miles from the Volcano House, and for four or five miles towards Glenwood, so that the entire area covered by the debris of explosive eruptions is estimated at more than sixty square miles. They are six feet thick in the new road around Kilauea iki. The following section has been made out:

At the surface, small gravel stones with soil;
Gravel two feet thick;
Sand, becoming black below;
Another foot thickness of sand;
Pumice, a few inches thick, sometimes in pockets;
Rubble stones, some as large as cobbles;
Underlying rock.

The black seams are suggestive of a vegetable growth, indicating a lengthy period when plants were able to spread naturally from the surroundings, only to be covered later by the volcanic rain.

The enormous area thus covered with explosive material renders it probable that the comparatively mild discharge of 1790 was inadequate to account for so extensive an inundation. There must have been several such discharges, perhaps recurring during centuries of time. Only a tithe of the stones spread over the surface would have been needed to destroy a much larger detachment than that suffocated in 1790. It would seem more consonant with the facts to connect the prolific tuffaeous and scoriaeous discharges with the days of Liloa rather than of Keoua; and

perhaps Keanakakoi may have been the vent through which the discharge came.

Certain observations made in 1905 may be significant here:

Opposite Keanakakoi in the pit of Kilauea there was formerly exhibited upon the maps a "sulphur bank," now mostly covered by the black ledge. A narrow promontory still extends westerly to the south of Halemaumau, terminating at Kapuai and only slightly elevated, and covered with eolian debris. At the southwest end of the wall from Poli o Keawe there is an abrupt change from basalt to scoriae, and as you climb to this rock from the gravel a marked fault appears with a S.W. direction. On looking backwards there is a noticeable dip of the layers towards the old sulphur bank—perhaps of ten degrees. The fault seems to be the same with that figured by Professor W. H. Pickering.[33]

It seems apparent that the tuffs came from Keanakakoi, unless they represent the inward slope of the material blown out from Kilauea, such as falls toward the vent in tuff cones. Most of the cliff encircling the south curve of Kilauea is composed of similar materials.

Dr. Brigham speaks of several shallow pits in this tuff that were made by the falling down or washing into fissures the finer parts of the sand and gravel. All these facts impress one with the magnitude and unusual character of the materials erupted about Keanakakoi.

While there has been uncertainty about the date and origin of the various Kau accumulations of dust, it is refreshing to be able to present the views of Mr. E. D. Baldwin, obtained recently as the result of his survey for the Kapapala map. He finds that much of the fine volcanic ash has been derived from a Kilauean source; while there were earlier discharges in lower Kau and at Ka Lae not thus accounted for. These have been mentioned elsewhere in connection with the history of Mauna Loa.

E. D. BALDWIN UPON THE YELLOW ASHES OF KAU.

As to the sources of the yellow ash eruption, I would state, that I found a partial old yellow cone in among the Kamakaia hills, or the hills some three miles back of the Halfway House. The first source of the 1823 flow was three miles above these hills, from a long fissure, and then it seems to have broken out again, in its line of flow at these hills, forming the two larger cones. Near the large cone are two ancient cones, surrounded by the new lava, one of these was completely spattered and plastered over

[33] Hawaiian and Lunar Craters Compared, Fig. 39.

by the ejections from the large cone; it was on this cone, while riding along its base, that my horse broke through the crust, and while floundering around for a footing brought up large quantities of yellow tufa, of exactly the same nature as the black tufa, only it was of a beautiful yellow ocher color. On investigation I found that a large portion of this cone was composed of the same material.

About a mile below Kamakaia hills, in the middle of the 1823 flow, is what we call the yellow cone. This cone had attracted my attention several times from a distance, as being of a yellowish color on all sides that we had observed it from. I thought, of course, that like the little sharp cone, Puu Kou, between it and the Kamakaia hills, it was a portion of the 1823 lava flow, but when we went out to the cone, we found that it was the top of an old cone sticking up through the 1823 flow, which flow had run all around the same, and into the crater of the cone. This cone was very interesting, its formation was exactly the same as all of the dark colored tufa cones, with the exception of color, which was entirely of the yellow tufa, which, when crushed in the hand to fine powder, had exactly the same appearance as the Kau yellow soils. In the crater of the cone were the same brilliantly red tufas that you find in the craters of all other cones. The top of the cone stands forty or fifty feet above the 1823 flow, and must be several hundred feet in circumference at the flow line. At this point the land lays more or less level, with a gentle slope towards the sea, so that the 1823 flow seems to have piled up to a great height and spread out to over a mile wide; showing that this was a very large cone in its original state.

There are further evidences of the yellow eruptions some ten miles from these cones mentioned above. The great hill Puu Kapukapu, at the sea coast, is largely composed of the Kau yellow soil, also just to the Kau side of this hill, is the great hill Puu Kaone, having a low flat top, containing sixty acres of first class agricultural land, composed entirely of the Kau yellow soil, of a depth of over thirty feet, as observed in the little rain-washed gullies on the same. Also on the face of the great pali or fault line, near the top, on a line towards Kamakaia hills from Puu Kapukapu, I noticed a large yellow patch.

None of the sources of the yellow eruptions, that I have mentioned, would account for the lower Kau yellow soil, and that on the Kau side of Ka Lae or South Point, as the prevailing winds in this district seem to sweep from the volcano (Kilauea) down past the Kamakaia hills, and from there they meet the

winds coming around from the sea coast, which seem to turn the air currents inland again.

My theory is, that at some ancient period, there was a great line of yellow eruptions, extending from Puu Kapukapu (near Keauhou), past the Kamakaia hills to the lower portion of Kau, and that the sources of this yellow eruption in the lower part of Kau have been covered up with later flows, or other volcanic action, and that the great beds of yellow soil that we find today all over Kau, were blown there from these sources, before they were covered up. All of the yellow soil on the Pahala plantation, or towards the volcano from Pahala, is directly on the line of the prevailing winds from the direction of Kamakaia hills, Yellow cone, and a short ways below the same. I have especially noticed in the cuts on the Volcano-Kau road, just above the Pahala mill, that the old aa formation seems to be full of this yellow dust. If one will go and study the action of the wind on the great masses of volcanic sand being blown, at present, from Kilauea towards Kamakaia hills, it will be noted that when this sand strikes an aa flow, its forward progress is stopped, until it has filled and sifted into all of the little crevices of the aa. From Kilauea to near Kamakaia hills is a nearly barren field of pahoehoe, and the sand is driven along this space at a great pace, until it reaches the aa at the Kamakaia hills, and there it has been blocked up and is in many cases forming numerous sand dunes. Some of these sand dunes are very extensive, being four or five hundred feet long and over fifty feet high.

ELLIS' DESCRIPTION OF KILAUEA.

The first edition of the *Journal of the Tour Around Hawaii* was published in 1825. Eight years later it was reprinted with additions and emendations as *Polynesian Researches,* in four volumes and some of the original statements were modified. There were English editions also. I will utilize the additions and corrections given in the later edition.

"We found ourselves," he says, "on the edge of a steep precipice (Uwekahuna) with a vast plain before us," seven and one-half miles in circumference, and sunk at least eight hundred feet "below its original level. The surface of this plain was uneven, and strewed over with large stones and volcanic rocks." A place was found at the north end where a descent to the plain below was found practicable, and even yet the stones gave way under their feet causing them to fall and receive bruises. The rocks were of a "light red and gray lava, vesicular, and lying in horizontal

strata, varying in thickness from one to forty feet. In a small number of places the different strata of lava were also rent in perpendicular or oblique directions, from the top to the bottom, either by earthquakes or other violent convulsions of the ground connected with the action of the adjacent volcano." "The immense gulf has the form of a crescent two miles long from northeast to southwest and a mile in width." "The bottom was covered with lava, and the southwest and northern parts of it were one vast flood of burning matter, in a state of terrific ebullition, rolling to and fro its "fiery surge" and flaming billows. Fifty-one conical islands (spiracles), of varied form and size, containing as many craters, rose either round the edge or from the surface of the burning lake. Twenty-two constantly emitted columns of gray smoke or pyramids of brilliant flame; and several of these at the same time vomited from their ignited mouths streams of lava, which rolled in blazing torrents down their black indented sides into the boiling mass below."

Next follows a paragraph added in the later edition, a theoretical deduction. "The existence of these conical craters led us to conclude that the boiling caldron of lava before us did not form the focus of the volcano; that this mass of melted lava was comparatively shallow; and that the basin in which it was contained was separated, by a stratum of solid matter, from the great volcanic abyss, which constantly poured out its melted contents through these numerous craters into this upper reservoir. We were further inclined to this opinion from the vast column of vapor continually ascending from the chasms in the vicinity of the sulphur banks and pools of water, for they must have been produced by other fire than that which caused the ebullition in the lava at the bottom of the great crater; and also by noticing a number of small craters in vigorous action, situated high up the sides of the great gulf, and apparently quite detached from it. The streams of lava which they emitted rolled down into the lake and mingled with the melted mass, which, though thrown up by different apertures, had perhaps been originally fused in one vast furnace."

"The sides of the gulf before us, although composed of different strata of ancient lava were perpendicular for about (nine) hundred feet (as calculated by Lieut. Malden later) and rose from a wide horizontal ledge of solid black lava of irregular breadth, but extending completely round. Beneath this ledge the sides sloped gradually towards the burning lake, which was, as nearly as one could judge, three or four hundred feet lower. It was evident that the large crater had been recently filled with liquid lava up to the black ledge, and had by some subterranean

canal emptied itself into the sea, or upon the lowland on the shore." And he goes on to suggest that this discharge was what they had seen at Ponahoahoa a short time previously. This eruption is reported at one time two moons and at another five moons earlier than that date of August 1st. I have already presented a figure illustrating this flow to the southwest.

It has been difficult to be entirely satisfied with some of the details offered in this sketch, because of repetitions, and of differences in the accompanying sketches. The first are explained by the supposition that to the original statement additions were made by others of the party; and the second may be due to the artist or engraver who make changes to suit fancy. The earlier account of all the Hawaiian volcanoes have been more or less influenced by a supposed similarity to Vesuvius. Instead of reproducing the sketches, I will present a restoration of what seem to me to be the true delineation of the cliffs, the black ledge and the lakes of fire, as they appeared in 1823, Plate 27B. The verbal description of the volcano given above by Mr. Ellis represents things as seen from Uwekahuna, but the views published must have been taken from the opposite side of the pit, showing the place on which he stood when he obtained his impressions.

The descriptions of the two sulphur banks correspond to what have been seen later by others. The one at the north end was said to be about one hundred and fifty yards long, and thirty feet high at the maximum, showing much sulphur mixed with red clay. The ground was hot, fissures seamed the surface through which thick vapors continually ascended. Fine crystals of sulphur appeared in acicular light yellow prisms near the surface; those lower down were of an orange-yellow color in single or double tctrahedral pyramids an inch long. Ammonium sulphate, alum and gypsum frequently incrusted the stems. The other sulphur bank was larger and the sulphur more abundant, but they did not find time to examine it carefully. Both these banks correspond to what is now called a solfatara.

The view by night was impressive. "The agitated mass of liquid lava, like a flood of melted metal, raged with tumultuous whirl. The lively flame that danced over its undulating surface, tinged with sulphureous blue, or glowing with mineral red, cast a broad glare of dazzling light on the indented sides of the insulated craters, whose roaring mouths, amid rising flames and eddying streams of fire, shot up, at frequent intervals, with very loud detonations, spherical masses of fusing lava or bright ignited stones."

Mr. Ellis correctly named the rock, calling it basalt containing

fine grains of feldspar and augite, with olivine. He also found zeolites and described the volcanic glass called Pele's hair by the natives. He conceived it to have been produced by a separation of fine spun threads from the boiling fluid, and when borne by the smoke above the edges of the crater had been wafted by the winds over the adjacent plain. He examined several of the small craters, which from above had appeared like mole hills, and found them to be from twelve to twenty feet high. The outside was composed of bright shining scoria and the inside was red with a glazed surface. He also entered several tunnels through which the lava had flowed into the abyss, and correctly ascribes their origin to the formation of the roof and sides by the cooling of the exterior, while the liquid for a time continued to flow in the inside. Professor Dana thinks that the fan figured on the west wall in the first sketch of the south end of the volcano was one of these tunnels, but it seems to me that it was only a fan of gravelly scoriae. It appeared as an isolated cone in the second sketch, detached from the wall, probably because the engraver did not know what else to do with it. Dr. S. E. Bishop tells me that this fan was very conspicuous when he first visited the volcano seventy years ago, and at his suggestion I looked for it in 1905 and could identify its location. Probably the tunnels were upon the eastern side, where later flows, such as those made in 1832, are still in evidence. These tunnels were represented as being hung with red and brown stalactitic lava, while the floor appeared like one continued glassy stream. The riffle of the surface was as well defined as if the lava had suddenly stopped and become indurated before it had time to settle down to horizontality.

It would appear from what has been stated that there was more than one lake of fire at this time, and that there was a great abyss into which the surplus lava from the higher lake and the streams through the tunnels had accumulated. Mr. Ellis also speaks of the two side craters Keanakakoi and Kilauea iki, thus proving that these names were in use in 1823, and he seems to have been the originator of the expression "black ledge," which represented the level assumed by the molten lava before the recent discharge to the southwest. He speaks of many masses of grey basaltic rock, weighing from one to four and five tons, and surmised that they had been ejected from the great crater during some violent eruption. Not to present more of his truthful descriptions, I will refer only to his final speculation of the extent of the present subterranean fires. The whole island of Hawaii was said to be "one complete mass of lava, or other volcanic matter in different stages of decomposition. Perforated with innumerable apertures

in the shape of craters, the island forms a hollow cone over one vast furnace, situated in the heart of a stupendous submarine mountain, rising from the bottom of the sea," etc.[84]

THE BELIEF IN PELE.

"The apprehensions uniformly entertained by the natives of the fearful consequences of Pele's anger prevented their paying very frequent visits to the vicinity of her abode; and when, on their inland journeys, they had occasion to approach Kilauea, they were scrupulously attentive to every injunction of her priests, and regarded with a degree of superstitious veneration and awe the appalling spectacle which the crater and its appendages presented. The violations of her sacred abode, and the insults to her person, of which we had been guilty, appeared to them, and to the natives in general, acts of temerity and sacrilege; and, notwithstanding the fact of our being foreigners, we were subsequently threatened with the vengeance of the volcanic deity under the following circumstances.[85]

"Some months after our visit to Kirauea, a priestess of Pele came to Lahaina, in Maui, where the principal chiefs of the islands then resided. The object of her visit was noised abroad among the people, and much public interest excited. One or two mornings after her arrival in the district, arrayed in her prophetic robes, having the edges of her garments burnt with fire, and holding a short staff or spear in her hand, preceded by her daughter, who was also a candidate for the office of priestess, and followed by thousands of the people, she came into the presence of the chiefs; and having told who she was, they asked what communcations she had to make. She replied that, in a trance or vision, she had been with Pele, by whom she was charged to complain to them that a number of foreigners had visited Kilauea; eaten the sacred berries; broken her houses, the craters; thrown down large stones, etc.—to request that the offenders might be sent away,—and to assure them, that if these foreigners were not banished from the islands, Pele would certainly in a given number of days, take vengeance, by inundating the country with lava, and destroying the people. She also pretended to have received in a supernatural manner, Rihoriho's approbation of the request of the goddess. The crowds of natives who stood waiting the result of her interview with the chiefs were almost as much astonished as the priestess herself, when Kaahumanu, and the other

[84] Polynesian Researches, Vol. IV, pp. 174 to 198 passim.
[85] P. 202, Vol. IV, Polynesian Researches, William Ellis, 1833.

chiefs, ordered all her paraphernalia of office to be thrown into the fire, told her the message she had delivered was a falsehood, and directed her to return home, cultivate the ground for her subsistence, and discontinue her deceiving the people.

"This answer was dictated by the chiefs themselves. The missionaries at the station, although they were aware of the visit of the priestess, and saw her, followed by the thronging crowd, pass by their habitation on the way to the residence of the chiefs, did not think it necessary to attend or interfere, but relied entirely on the enlightened judgment and integrity of the chiefs, to suppress any attempt that might be made to revive the influence of Pele over the people; and in the result they were not disappointed, for the natives returned to their habitations, and the priestess soon after left the island, and has not since troubled them with threatenings of the goddess.

"On another occasion, Kapiolani,[36] a royal princess, the wife of Naihe, chief of Kaavaroa, was passing near the volcano, and expressed her determination to visit it. Some of the devotees of the goddess met her and attempted to dissuade her from her purpose; assuring her that though foreigners might go there with security, yet Pele would allow no Hawaiian to intrude. Kapiolani, however, was not to be thus diverted, but proposed that they should all go together; and declaring that if Pele appeared, or inflicted any punishment, she would then worship the goddess, but proposing that if nothing of the kind took place, they should renounce their attachment to Pele, and join with her and her friends in acknowledging Jehovah as the true God. They all went together to the volcano; Kapiolani, with her attendants, descended several hundred feet towards the bottom of the crater, where she spoke to them of the delusion they had formerly labored under in supposing it inhabited by their false gods; they sang a hymn, and after spending several hours in the vicinity, pursued their journey. What effect the conduct of Kapiolani, on this occasion, will have on the natives in general, remains to be discovered."

KAPIOLANI.

BY ALFRED, LORD TENNYSON.

When from the terrors of nature a people
Have fashioned and worshipped a Spirit of Evil,
Blest be the voice of the teacher who calls to them,
"Set yourselves free!"

[36] Kapiolani was the daughter of Keawemauhile, the former king of Hilo, slain by Keoua in 1790.

Noble the Saxon who hurled at his idol
A valorous weapon in olden England!
Great, and greater, and greatest of women,
Island heroine, Kapiolani,
Clomb the mountain, and flung the berries,
And dared the Goddess, and freed the people
        Of Hawaii!
This people,—believing that Pele the Goddess,
Would swallow in fiery riot and revel
        On Kilauea,
Dance in a fountain of flame with her devils,
Or shake with her thunders and shatter her island,
        Rolling her anger
Through blasted valleys and flowing forest
In blood-red cataracts down to the sea!

* * * * * *

Long as the lava light glares from the lava lake,
        Dazing the starlight;
Long as the silvery vapor in daylight
Over the mountain floats, will the glory
Of Kapiolani be mingled with either
        On Hawaii.
What said her Priesthood,
"Woe to this island if ever a woman should handle
Or gather the berries of Pele! Accursed were she!
And woe to this island if ever a woman
Should climb to the dwelling of Pele the Goddess!
        Accursed were she!"

* * * * * *

One from the sunrise dawned on His people,
And slowly before Him vanished shadow-like
        Gods and Goddesses,
None but the terrible Pele remaining,
As Kapiolani ascended her mountain,
Baffled her priesthood, broke the tabu,
        Descended the crater,
Called on the Power adored by the Christian,
And crying, "I dare her! Let Pele avenge herself!"
Into the flame dashed down the berries,
And drove the demon from Hawaii!

THE TRUE STORY OF PELE.

King Kalakaua recovered from the traditions handed down for many generations the true story of Pele, and has presented it in

his book under the heading of *The Apotheosis of Pele.* It seems that there was a large family, five brothers and nine sisters, emigrating from Tahiti during the reign of Kamiole the usurper about A. D. 1175. Their names are given by Ellis as follows: Kamohoarii; Tapohaita hiora (the explosion in the place of life); Teuaatepo (the rain of night; Tanehetiri (husband of thunder or thundering Tane) and Teoahitamatana (fire-thrusting child of war). These were all brothers, two of them like Vulcan being humpbacked. The sisters were Pele, the principal goddess; Makorewawahiwa (fiery-eyed canoe breaker); Hiataholani (heaven-rending cloud holder); Hiatanoholani (heaven-dwelling cloud holder); Hiatata aravamata (quick-glancing-eyed cloud holder, or the cloud holder whose eyes turn quickly and look frequently over her shoulders); Hiatahoiteporiopele (the cloud holder embracing or kissing the bosom of Pele); Hiatatabuenaena (the red-hot mountain holding or lifting clouds); Hiatatareia (the weather garland-encircled cloud holder); and Hiataopio (young cloud holder).

This family with many others in their train settled about Kilauea. Pele was a valiant warrior. Kamapuaa was attracted by the merits of Pele, visiting Kilauea, and made proposals to become her guest and suitor. In many of the annals he is represented as half human and half hog—but Kalakaua explains that he was simply a rough, stalwart man with coarse black bristly hair of unprepossessing appearance, and called a half hog in derision. Pele rejected his proposals with contempt, calling him a hog and the son of a hog. A combat ensued, and the Pele family were worsted, and retreated to one of the long volcanic tunnels marking the course of an earlier lava flow ,and the entrance was closed. The party consisted of two men and eighteen women and children. Kamapuaa finally discovered the retreat and dug down into it from above. Just then there came a flow of lava which drove away the besiegers, who believed the people within the cave had been destroyed. Because of this timely eruption it was believed that Pele had the power of calling up the fire, and she became apotheosized as a goddess. As time went on the various eruptions were ascribed to some of Pele's movements. The whole island was considered bound to pay tribute; and if the proper offerings were not given to her votaries the caldera would be filled with lava and made to follow the delinquents.

KILAUEA IN 1824.

In 1824 Kilauea was visited by E. Loomis,[37] June 16th, who came from the southwest. After reaching a point two miles from the crater he was annoyed by smoke blowing in his face, accompanied by sulphur fumes. The air, too, was filled with fine particles of sand, rendering it necessary to protect his face from their impact; and the surface of the ground was covered by it, his feet sinking into it six or eight inches at every step. From crevices five miles west of the crater smoke was issuing, and occasionally the forced ejection was great enough to produce an irregular hissing sound. At the southwest end of the volcano the smoke was so dense that little could be seen, and farther on much rain fell. He took the road on the east side. From two hundred and fifty to three hundred feet below the edge was a level platform, extending entirely around the crater, which was evidently the "black ledge" of Ellis. This platform was fifteen rods wide where he descended, probably near the "sulphur banks" as now designated. He had little difficulty in reaching the black ledge. Having now descended six hundred feet ,Mr. Loomis walked upon the lower platform whose surface was smooth, though not level, rising in heaps like cocks of hay and broken by innumerable fissures.

The lava was black, porous like pumice, and traversed by crevices emitting very hot steam. Proceeding eight or ten rods he reached another escarpement of two hundred or three hundred feet deep leading to the floor of the most active portion, from which smoke and flames of fire were issuing. There seemed to be small craters (spiracles) where the fire burst forth attended by a horrid noise. He was quite disappointed in not finding this lowest platform a mass of liquid fire, as it had been the year previous. The surface had become hard, and he presumed he could have walked over it safely but he did not descend to it as the sides were too steep to allow of a comfortable passage. This record is quite important, as it shows a period of comparative quiet at the center of eruption following the intense activity reported by Ellis in the previous year.

VISIT OF LORD BYRON.

In the year 1825, July 28th, a party from the "Blonde" visited the crater, Lord George Anson Byron being the leader. Others were Rev. C. C. Stewart and Lieut. Malden, the historians, and R. Dampier, the artist.

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[37] From an unpublished journal, printed by W. T. Brigham.

The hut used by the company was situated upon the narrow plain between Kilauea and Kilauea iki. It had been erected a year or two earlier for the accommodation of Kapiolani. Lieut. Malden calculated the height of the upper cliff, Uwekahuna, to be nine hundred feet above the black ledge, and the depth of the lower pit at six hundred feet, a total of 1,500 feet. The circumference of the edge of the black ledge was from five to seven miles and that of the top from eight to ten miles.

Mr. Stewart speaks of the black ledge as a kind of gallery, in some places only a few feet, in others many rods wide. The gulf below contains as many as sixty small conical craters, many in constant action. The tops and sides of two or three of these are covered with sulphur, showing mingled shades of yellow and green. The upper cliffs on the northern and western sides are of a red color. Those on the eastern side are less precipitous and are largely composed of sulphur. The south end was wholly obscured by smoke which was impenetrable. The chief seat of action seemed to be at the southwestern end (Halemaumau). To the north of this is one of the largest of the smaller craters—one hundred and eighty feet high—an irregularly shaped inverted funnel of lava covered with clefts, orifices and tunnels, from which bodies of steam escaped with deafening explosion, while pale flames, ashes, stones and lava were propelled with equal force and noise from its ragged and yawning mouth.

On the evening of the following day (29th) after terrific noises and tremblings of the ground, "a dense column of heavy black smoke was seen rising from the crater directly in front of us—the subterranean struggle ceased—and immediately afterwards flames burst from a large cone, near which we had been in the morning, and which then appeared to have been long inactive. Red-hot stones, cinders and ashes, were also propelled to a great height with immense violence; and shortly after the molten lava came boiling up, and flowed down the sides of the cone and over the surrounding scoriae, in two beautifully curved streams." At the same time a lake of molten lava two miles in circumference made it appearance.

Rev. Artemas Bishop, in December, states that the pit was not so deep as in 1823 at the time of Ellis' visit by as much as four hundred feet. There were also lakes of lava, frequently discharging gusts of vapor and smoke with great noise. As an evidence of oft repeated eruptions from Kilauea, the natives remarked to Mr. Bishop, that after rising a little higher the lava would discharge itself towards the sea through some subterranean aperture.

Rev. Mr. Stewart visited Kilauea again in October, 1829. The

lower pit had been filled up more than two hundred feet, and there was more fire at the northern end. Many of the cones had disappeared, but he was greatly interested in two of them—each one about twenty feet high—tapering from a point above to a base sixty feet in circumference. They were hollow, with steam, vapors and flame issuing from crevices and roaring so as to merit the appellation of "blow holes," or "spiracles," as named by G. Poulett Scrope.

VISIT OF HIRAM BINGHAM.

Rev. Hiram Bingham spent thirty hours at the volcano October 20th and 21st, 1830. He represented the altitude to be 4,000 feet, ten thousand below Mauna Loa. Six hundred feet below the rim "stretched around horizontally a vast amphitheater gallery of black indurated lava," on which a hundred thousand people might stand. The lake of fire was one thousand feet deep. "The fiercely whizzing sound of gas and steam, rushing with varying force through obstructed apertures in blowing cones, or cooling crusts of lava, the laboring, wheezing struggling, as of a living mountain, breathing fire and smoke and sulphurous gas from his lurid nostrils, tossing up molten rocks or detached portions of fluid lava ,and breaking up vast indurated masses with varied detonations, all impressively filled us with awe.

"The great extent of the surface of the lava lake; the numerous places on it where the fiery element was displaying itself, the conical mouths here and there, discharging glowing lava overflowing and spreading its waves around, or belched out in detached and molten masses that were shot forth with detonations, perhaps by the force of gases struggling through from below the surface, while the vast column of vapor and smoke ascended up toward heaven ,and the coruscations of the emitted brilliant lava illuminated the clouds that passed over the terrific gulf, all presented by night a splendid and sublime panorama of volcanic action, probably nowhere else surpassed."

He descended from the northeast side to the black ledge, and to the lava lake, which "presented cones, mounds, plains, vast bridges of lava recently cooled, pits and caverns, and portions of considerable extent in a movable and agitated state." Near the center is a large mound, from the top of which lava poured out in every direction in a series of circular waves. The outermost wave solidifies, when another one follows, perhaps passing over the first; then others follow as if in a series of pulsations from the "earth's open artery" at the top of the mound.

The capillary glass was observed, and its formation understood. "It is formed, I presume, by the tossing off of small detached portions of lava of the consistence of molten glass, from the mouths of cones, when a fine vitreous thread is drawn out between the moving portion and that from which it is detached. The fine spun product is then blown about by the wind, both within and around the crater, and is collected in little locks or tufts."[38]

In July, 1831, Mr. Goodrich visited Kilauea and says that "the crater had been filled up to the black ledge, and about fifty feet above it, about nine hundred feet in the whole," since his first visit in 1823.

ERUPTION OF 1832.

The accounts of the eruption of 1832 are sufficiently full to enable us to know that the disturbances in Kilauea near the lakes of fire correspond to those manifested at other eruptive periods. According to the statements that have already been cited, the lower pit had been filled up with lava to the amount of nine hundred feet since the discharge of 1823. Rev. Joseph Goodrich visited the locality in November and says that the lava "had now again sunk down to nearly the same depth as at first, leaving as usual a boiling caldron at the south end. The inside of the crater had entirely changed. * * * In January preceding—about the 12th as nearly as I can ascertain—the volcano commenced a vigorous system of operations, sending out volumes of smoke; and the fires so illumined the smoke that it had the appearance of a city enveloped in one general conflagration."[39] A day or two later there were six or eight smart earthquakes, repeated for two or three days. These may have been concerned more particularly with the emissions on the plain between the two craters of Kilauea and Kilauea iki.

On descending into the caldera, Mr. Goodrich speaks of the molten lava at the south end—"an opening in the lava sixty to eighty rods long, and twenty or thirty wide." About twenty feet below the brink this liquid mass was "boiling, foaming and dashing in billows against the rocky shore. The mass was in motion, running from north to south at the rate of two or three miles an hour; boiling up as a spring at one end, and running to the other." He speaks of this mass as a *lake,* and says that the liquid lava is incrusted by its own cooling, just as ice is formed

[38] A residence of twenty-one years in the Sandwich Islands, by Hiram Bingham, A.M., Third Edition, 1855.
[39] American Journal of Science, XXV, p. 201.

over rivers in cold climates. As the ice in rivers crashes against the shores, so this crust is forced against the bank and distorted. The lava crusts melt and reform while "gaseous matter is forced through, scattering the liquid fire in every direction." There were also two islands in this lake.

This, however, must have been after the discharge of the liquid from the bottom of the pit. There is absolutely no testimony from any source, of this eruption, save the statement that it ran away about January 12th. Whether it appeared at the surface, filled up some subterranean cavity or flowed under the sea is entirely unknown. Before its disappearance the lava rose about fifty feet above the black ledge of 1823, thus building up a platform believed to be nine hundred feet above the molten lake.

From Mr. Goodrich's statements the depth of the bottom must have been 1,750 feet from the top of the wall. This is confirmed by an entry in the private diary of Rev. W. P. Alexander who visited the volcano January 12, 1833, two months later than Mr. Goodrich, who says the crater was two thousand feet deep. He does not speak of any black ledge; whence it is inferred that this terrace must have been very narrow, as in 1823. Mr. Alexander was disappointed in not finding the principal furnace in lively action while he was at the bottom of the pit; but by the time he had returned to the summit a furious action had commenced and molten lava spouted far into the air with a roaring sound. The following day the boiling caldron was found to be 3,000 feet long, 1,000 wide, and spouting in jets forty or fifty feet high.

The manifestations of igneous activity in another part of the area, at this time, January, 1832, as reported by Mr. Goodrich and confirmed by later observations of the effects produced, were unlike any others that have been seen at Kilauea. "The earthquakes rent in twain the walls of the crater on the east side from the top to the bottom, producing seams from a few inches to several yards in width, from which the region around was deluged with lava. * * * The chasms" (were developed) "within a few yards of where Mr. Stewart, Lord Byron, myself and others had slept," the spot being the "Hut" on Malden's map, "so that the spot where I have lain quietly many times is entirely overrun with lava." Back of it, at right angles with the main chasm, and about half way up the precipice, there was a vent a quarter of a mile in length from which the lava issued which had destroyed the Hut. This fissure thus was parallel with the edge of Kilauea.

Upon Mr. Dodge's map the lava is represented as starting from an orifice below the edge of Poli o Keawe, spreading out like a

fan so as to include the Hut, and then turning westerly so as to pour into Kilauea; and there was so much of it that it makes a tongue-like projection into the contour of the lower plain just at the northern end of the sulphur banks. Professor Dana was greatly impressed by the appearance of these cooled and hollow streams, as he saw them in 1840. "The angle of descent of these streams was about thirty-five degrees; and yet the streams were continuous. The ejection had been made to a height of four hundred feet at a time when the pit below was under boiling lavas and ready for discharge. Elsewhere about the upper walls, and also about those of the lower pit, no scoria was seen. The surfaces of walls are those of fractures, brought into sight by subsidences; and the rocks of the layers were as solid as the most solid of lavas. Moreover, no scoria intervened between the beds of lava even in the walls of the lower pit, each new stream having apparently melted the scoria-crust of the layer it flowed over; and no beds of cinders or volcanic ashes were anywhere to be seen in alternation with the beds of lava. While the cooled lava streams over the bottom were of the smooth-surfaced kind, and would be called pahoehoe, there was the important distinction into streams having the scoria-crust just mentioned, and those having the exterior solid with no separate crust—facts that pointed to some marked difference in conditions of origin."

The floor of Kilauea iki is covered by as many as fifty hummocks fifteen or twenty feet high. They arrested the attention of Professor W. H. Pickering in 1905, who conceives them to illustrate the process of construction of Kilauea itself as well as elevations on the surface of the moon. He says, "The surface of the crater floor of Kilauea iki seems to have solidified into a layer six to ten inches in depth and distinct from the portions below it. * * * A liquid core forced up from below raised this surface layer locally, and shattered it into separate pieces like cakes of ice. This core in the case of the smaller craterlets was sometimes only two or three feet in diameter, and could be seen beneath the shattered surface. In one instance its summit seemed to have an almost globular form, five feet in diameter. If the volcanic forces beneath these craterlets had been more intense, it is probable that the issuing lava would have completely destroyed them, forming a series of crater pits into which the lava would have subsequently retreated. In the southwest part of the floor two such pits were found, perhaps fifteen feet in depth by thirty in diameter, down into which a stream of lava had poured, but had solidified without filling them up."[40]

[40] Lunar and Hawaiian Physical Features Compared, p. 166.

Kilauea iki, according to Mr. Dodge's map, is 3,300 feet from east to west and 2,800 feet from north to south, and is seven hundred and forty feet deep, or eight hundred and sixty-seven feet below the Volcano House, from which it is about a mile distant. It is best reached by descending the north wall, making use of ropes in the steepest part of the slope. It is now (1909) encircled by a carriage road from the Volcano House.

This was the original name given to it by the natives, *iki,* meaning little, and was used by Mr. Ellis in his Journal, and by most travelers. Professor Brigham called it Poli o Keawe, and applied the Kilauea iki to Keanakakoi; and was followed by Captain Dutton. On questioning reliable natives in 1883 about the nomenclature, I found that Mr. Ellis was right in his early application of these names, and that the expression Poli o Keawe, signifying the *bosom of Keawe,* should be applied to the bluff overlooking Kilauea between the two side pits. Keanakakoi was derived from *ana,* a cave, and *koi* an axe or adze: meaning a chipping axe cave, because stone implements had been manufactured here in primitive times. The same name is applied to the famous locality for the manufacture of implements situated near the summit of Mauna Kea.

On further investiagtion I have discovered that Professor Brigham has improperly represented that Mr. Goodrich endorsed two names relating to Kilauea.[41] The first is Halemaumau and the second is Poli o Keawe. He has made an abstract of Mr. Goodrich's statement, as partially quoted above, into two sentences amounting to seventy-eight words, including the two geographical names, and has included the whole in quotation marks. Neither of the expressions Halemaumau or Poli o Keawe were used by Mr. Goodrich, although he describes both the localities. Professor Brigham probably did not intend to intimate that Mr. Goodrich used the words indicated.

It is worthy of note that for a short time eruptions may have taken place simultaneously from Kilauea and Mokuaweoweo in 1832. The first one commenced action January 12th and the second June 20th. We have, however, no definite statement from any one that the discharge from Kilauea continued as late as to the opening of the fire streams upon Mauna Loa, though it is not improbable.

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[41] See Notes on Volcanoes of the Hawaiian Islands by William T. Brigham, p. (69), 409; from Memoirs of the Boston Society of Natural History, Vol. I, Part III.

BETWEEN 1832 AND 1840.

The next visit to Kilauea recorded was by Mr. David Douglass in 1834. He found two molten lakes—the more northern three hundred and nineteen yards in diameter; the more southern, 1,190x700 yards in extent, and heart-shaped. The larger one occasionaly boiled with terrific grandeur, throwing up jets estimated to be from twenty to seventy feet high. Nearby stood a chimney forty feet high, "which occasionally discharged its steam as if all the steam-engines in the world were concentrated in it." Professor Dana says this is a good description of a blowing cone, though this name had not been used so early. Mr. Douglass measured the velocity of the movement in the lava by timing the rapidity of blocks of stone thrown upon the surface of the stream, just as one may estimate the velocity of water by the chips upon the top. This proved to be nearly three and a quarter miles per hour. Mr. Douglass used the barometer to determine the depths of the black ledge and pit. As the mean of two calculations he found the depth from Uwekahuna to the former to be seven hundred and fifteen feet, and to the bottom of the pit 1,077 feet, or three hundred and sixty-two feet below the black ledge. In addition to this he said it was forty-three feet more to the liquid lavas. This proves that there had been a renewal of the lava from the pit in 1832, and his other observations represent that the lower portion was larger and deeper than after the eruption of 1840. Douglass has been discredited because he seemed to have exaggerated the size and activity of Mokuaweoweo in a letter written to Dr. Hooker, dated three days later than the very reasonable account of the phenomena mentioned above. It has been suggested that he wrote the latter under the influence of temporary hallucination.

Charles Burnham says the crater was eight hundred feet deep over the whole surface in 1835 with no cones over seventy-five feet high. A very large lake visible from the hut. From the record book June 17, 1881.

In August, 1837, Mr. S. N. Castle of Honolulu visited Kilauea, and reported that the lower pit below the black ledge was nearly filled up, and he also found active cones in all parts of the caldera.

In May, 1838, Captains Chase and Parker visited the volcano and some account of their trip was compiled by E. C. Kelley for the *American Journal of Science*. The lavas had nearly filled up the lower pit. Over its floor, about four square miles in extent, there were twenty-six cones, eight of which were throwing out cinders and molten lava. Six small lakes were in evidence. The

largest one was probably identical with the later Halemaumau, upon whose surface an island of solid lava "heaved up and down in the liquid mass, and rocked like a ship on a stormy sea." They also noted the oscillations in the heat, so obvious to later visitors. The lake which had been boiling violently became covered by a mass of black scoriae; but this obscuration was temporary, for very soon this crust commenced cracking, black plates floated upon the surface like cakes of ice upon water, and probably disappeared. At the last moment of observation about a quarter of the floor gave way and became a vast pool of liquid lava.

An elaborate drawing of the volcano as it seemed at that time accompanies the sketch, prepared by a New York artist, who evidently incorporated into it the features of Vesuvius. It was taken from the south end, shows the great south lake and the floating island, and is of value because it indicates the nearly complete obliteration of the black ledge.

In August or September of the same year Count Strzelecki measured the height of the north-northeast wall with a barometer, finding it to be six hundred feet. Nothing is said about the black ledge, whence it may be inferred that it was not visible. Six craters filled with molten lava are mentioned, four of them three or four feet high, one forty feet and the other one hundred and fifty. Five of these had areas of twelve thousand feet each; and the sixth contained nearly a million and had the name of Haumaumau, and was encircled by a wall of scoriae fifty yards high. He said that the lava rose and sunk in all the lakes simultaneously —an observation that has never been confirmed in the later history. The language descriptive of the craters filled with lava might be interpreted to correspond with the occasional manifestation of a lake supported upon a rim consisting of the cooled liquid, as shown particularly in 1894. Like Mr. Douglass Count Strzelecki has given in the Hawaiian Spectator a more extravagant account of Kilauea, besides the reasonable one abridged above from a book upon New South Wales and Van Diemen's Land published seven years later. He was the first author to use the name Hau-mau-mau (Halemaumau).

The latest visit to the volcano previous to the great eruption in 1840 was made by Captain John Shepherd, R. N., September 16, 1839. He mentions several cones and small lakes on the floor of the pit on the way to the great lake. The black ledge was "obliterated": there were cones twenty to thirty feet high emitting lava and vapors with loud detonations; and the Great Lake, supposed to be Halemaumau, though incorrectly stated to be on the *east* side, was a mile and a half long, within a cone a hundred

feet high. There was an apparent flow of the liquid from south to north and spray thrown up from thirty to forty feet.

THE ERUPTION OF 1840.

This was the most important of all the discharges from Kilauea since the country has been known to us. Our sources of information are the statements of Rev. Titus Coan, Captain Charles Wilkes and Professor J. D. Dana. None of these gentlemen were on the spot at the time, but obtained their information from good authorities while the phenomena were fresh in mind.

Rev. Mr. Coan happened to be absent in Oahu at the time of the eruption. He had visited the volcano before and was familiar with its features; so that he was qualified to test the statements of the natives. The great basin below the black ledge had been filled to overflowing, and as much as fifty feet thickness had accumulated above the platform. The whole area of the pit is represented as an entire sea of ignifluous matter, with waves dashing against the walls sufficiently energetically as to detach great masses of the overhanging rocks. No one dared to approach near the fiery mass. Mr. Coan believed the statements correct, because not a single part of the lava seen after the eruption was like what had been visible before: all had been melted down and recast.

It was May 30th when the inhabitants of Puna first observed indications of fire. On the following day the fire greatly augmented. On the third day, June 1st, the lava began to flow off in a northeasterly direction. By the evening of June 3d the burning river had reached the sea and discharged over a cliff near Nanawale for three weeks. There were slight and repeated shocks of earthquakes near the volcano, for several successive days; but none were noticed at Hilo.

The first appearance of the lava was at a small pit about six miles distant from Kilauea, in the forest. The lava rose in this opening about three hundred feet, and then sank down when there was a discharge below. Remnants of this material were observed by Mr. Coan. Then there were other small ejections in fissures nearby. Others appeared, some two or three miles away, and finally upon June 1st began the principal outflow, twenty-seven miles from Kilauea, eleven from the sea, and 1,244 feet above tide water.

A further account of the eruption is given in the words of Mr. Coan:

The source of the eruption is in a forest and was not discovered at first ,though several foreigners have attempted it.

"From Kilauea to this place the lava flows in a subterranean gallery probably at the depth of a thousand feet, but its course can be distinctly traced all the way, by the rending of the crust of the earth into innumerable fissures and by the emission of smoke, steam and gases. The eruption in this old crater is small, and from this place the stream disappears again for the distance of a mile or two when the lava again gushes up and spreads over an area of about fifty acres. Again it passes underground for two or three miles, when it reappears in another old wooded crater, consuming the forest and partly filling up the basin. Once more it disappears, and flowing in a subterranean channel, cracks and breaks the earth, opening fissures from six inches to ten or twelve feet in width, and sometimes splitting the trunk of a tree so exactly that its legs stand astride at the fissure. At some places it is impossible to trace the subterranean stream on account of the impenetrable thicket under which it passes. After flowing underground several miles, perhaps six or eight, it again broke out like an overwhelming flood, and sweeping forest, hamlet, plantation and everything before it, rolled down with resistless energy to the sea, where leaping a precipice of forty or fifty feet, it poured itself in one vast cataract of fire into the deep below, with loud detonations, fearful hissings, and a thousand unearthly and indescribable sounds. Imagine to yourself a river of fused minerals, of the breadth and depth of Niagara, and of a deep gory red, falling in one emblazoned sheet, one raging torrent into the ocean. * * * The atmosphere in all directions was filled with ashes, spray, gases, etc., while the burning lava as it fell into the water was shivered into millions of minute particles, and being thrown back into the air fell in showers of sand on all the surrounding country. The coast was extended into the sea for a quarter of a mile, and a pretty sand beach and a new cape were formed. Three hills of scoria and sand were also formed in the sea, the lowest about two hundred and the highest about three hundred feet.

"For three weeks this terrific river disgorged itself into the sea with little abatement. Multitudes of fishes were killed, and the waters of the ocean were heated for twenty miles along the coast. The breadth of the stream where it fell into the sea, is about half a mile, but inland it varies from one to four or five miles in width, conforming, like a river, to the fall of the country over which it flowed. The depth of the stream will probably vary from ten to two hundred feet, according to the inequalities of the surface over which it passed. During the flow night was converted into day on all eastern Hawaii; the light was visible

for more than one hundred miles at sea; and at the distance of forty miles fine print could be read at midnight.

"The whole course of the stream from Kilauea to the sea is about forty miles. The ground over which it flowed descends at the rate of one hundred feet to the mile. The crust is now cooled, and may be traversed with care, though scalding steam, pungent gases and smoke are still emitted in many places. In pursuing my way for nearly two days over this mighty smouldering mass, I was more and more impressed at every step with the wonderful scene. Hills had been melted down like wax; ravines and deep valleys had been filled; and majestic forests had disappeared like a feather in the flame. On the outer edge of the lava, where the stream was more shallow and the heat less vehement, and where of course the liquid mass cooled soonest, the trees were mowed down like grass before the scythe, and left charred, crisp, smouldering and only half consumed." There are numerous vertical holes in the lava, almost as smooth as the calibre of a cannon, which represent the trunks of trees; they were too green to burn when the lava flowed around them but succumbed later to subaerial decay.

"During the progress of the descending stream, it would often fall into some fissure, and forcing itself into apertures, and under massive rocks and even hillocks and extended plots of ground, and lifting them from their ancient beds, bear them with all their superincumbent mass of soil, trees, etc., on its viscous and livid bosom, like a raft on the water. When the fused mass was sluggish, it had a gory appearance like clotted blood, and when it was active it resembled fresh and clotted blood mingled and thrown into violent agitation. Sometimes the flowing lava would find a subterranean gallery diverging at right angles from the main channel, and pressing into it would flow off unobserved, till meeting with some obstruction in its dark passage, when, by its expansive force, it would raise the crust of the earth into a dome-like hill of fifteen or twenty feet in height, and then bursting this shell, pour itself out in a fiery torrent around. A man who was standing at a consideable distance from the main stream, and intensely gazing on the absorbing scene before him, found himself suddenly raised to the height of ten or fifteen feet above the common level around him, and he had but just time to escape from his dangerous position, when the earth opened where he had stood, and a stream of fire gushed out."[42]

[42] Missionary Herald, Vol. XXXVII, p. 283.

PLATE 28.

Kilauea in 1840.

THE VISIT OF CAPTAIN WILKES.

Captain Wilkes of the United States Exploring Expedition made a prolonged stay at the two volcanoes in 1840-1, of which a full account is presented in the "Narrative," pp. 111-231. The part relating to Mauna Loa is given elsewhere. With this greater mountain in sight, Wilkes was quite disappointed when called to look at the uncouth black pits beneath his feet known as Kilauea. It was nothing but a depression, insignificant in comparison with the great plains and mountain, and exhibited scanty signs of fire. There was, however, a small cherry-red spot in the distance, above which was a cloud of silvery brightness. The depression itself, when properly examined, proved to be of grand proportions, three and a half miles long ,two and a half wide and nearly a thousand feet deep; and he says the city of New York might easily be placed within it and have room to spare. At night the immense pool of cherry-red lava in a state of violent ebullition illuminates the whole expanse, flowing in all directions. With him were over two hundred native Hawaiians crowded upon the brink, gazing upon the scene in terror, fearing the vengeance of Pele for trespassing upon her domain.

The descent into the pit was by the route used at the present day, starting at the Volcano House. First was the descent of six hundred and fifty feet to the platform known as the black ledge. Continuing upon this shelf for a mile, he stood directly over the lake of fire, three hundred and fifty feet below, 1,500 feet long and 1,000 feet wide. There was very little noise, and that was a low murmuring such as is heard in the boiling of a thick liquid. Occasionally masses of red-hot matter were ejected to the height of about seventy feet; then falling back. The lake was apparently rising, needing only a few feet of overflowing its banks.

The sketch made with the camera lucida by Mr. Drayton is reproduced, Plate 28, and is one of the best ever made of the volcano. It was taken from the north end. The lake of fire, which we know as Halemaumau, is in the distance. The vapors nearer arise from cracks in the lava, and consist of steam and sulphurous gases. The platform which seems perfectly level is the black ledge, which before the late eruption is supposed to have extended entirely across the lower pit. The shelf is from six hundred to 2,000 feet in width, seamed by crevices. It is not so smooth as it would appear, as it is covered by large pieces of lava, and in places rises into cones thirty or forty feet high. Here and there are huge tortuous masses stretched lengthwise like hideous fiery serpents with black vitreous scales.

The lower platform is like the upper in most respects. It may be covered by a scoriaceous vitreous layer, which crumbles and cracks under the feet. Small patches break like glass. The underlying basalt is firm and solid. A third variety is a black pumice. There are beneath, also, dark pits and vaulted caverns emitting blasts of heated air at the temperature of 180°. The floor is three hundred and eighty-four feet below the upper platform.

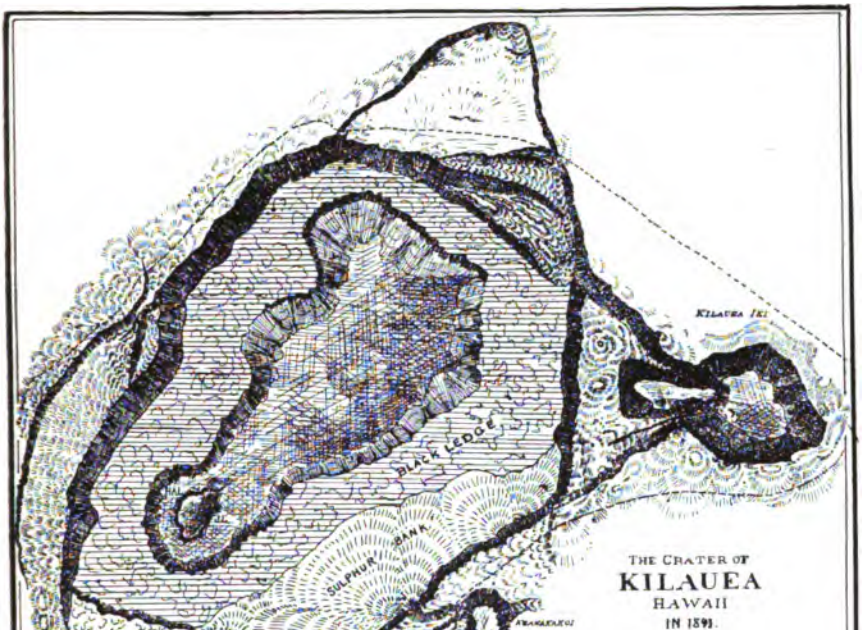
The lake because of its intense heat could not be approached nearer than 1,800-2,000 feet. It was discharging liquid matter at short intervals directly across the most convenient route of travel. The capillary glass, known as Pele's hair, abounded in the crevices in loose tufts like tow; and on the adjacent plain it adhered to bushes. These fibres may be straight with small drops of glass at one end, or crimped and frizzled, or may be spread over the ground like cobwebs.

On the return measurements were made and confirmed of all parts of the volcano, so that the data were obtained for a map and other illustrations. Dr. G. P. Judd, who had assisted very materially in managing the natives on the journey between Hilo and the summit of Mauna Loa, made the attempt to secure samples of the liquid lava. In pursuance of this quest he was gathering specimens of the capillary glass on the steep wall of the smaller lake, having been let down by hand through the assistance of natives. A slight movement in the lava arrested his attention. In a moment the crust was broken by a terrific heave and a jet of molten lava fifteen feet in diameter rose to the height of about forty-five feet with an appalling noise. In turning to escape he found himself under a projecting ledge and would have been overwhelmed except for the friendly assistance of Kalumo, a native Hawaiian. Both were badly scorched by the heat. Wilkes called this pit Judd's Lake, found to be thirty-eight feet deep and two hundred feet in diameter. It was filled up in twelve minutes.

As an illustration of the variation of the conditions, upon the night following the narrow escape of Dr. Judd, the larger lake sank down one hundred feet, thus discharging a mass of melted rocks measuring fifteen million cubic feet. The lava ascends from unknown depths, pours over the borders of the lake, and then there may be a sudden falling away of the liquid because it has found a way of escape into some cavern or to the exterior of the mountain low down. These small escapades are the same in principle with the larger infrequent so-called eruptions.

Plate 29 represents an attempt to delineate the interior of the volcano at the time of Wilkes' visit. The data employed are the

PLATE 29.



Map of Kilauea, 1841.

original maps of the Exploring Expedition and the later Government Surveys. Professor Dana has presented the details of the corrections needed by the Wilkes map which are all incorporated into this plate. It is assumed that there has not been a sufficient change in the position of the outer walls of the pit to show in a map of this scale. The black ledge and the pit are constantly changing. The special features of this map are the less depth of the walls back of the black ledge as compared with the early conditions reported by Ellis and Malden, but a greater depth than has been visible since; and the greater extent of the sulphur bank next to Keanakakoi. Wilkes' party encamped on the higher ground north of the volcano. The means are not in hand for a completely satisfactory representation of this "great lake" to which the name of Halemaumau belongs. This end of the lower pit is higher than the other.

J. D. DANA'S VISIT.

Mr. Dana was one of the scientific corps of the Exploring Expedition. It seems very strange that the geologist of the expedition was not directed to explore the volcanoes. The commander evidently wished to save that bit of work for himself; and it must have been a source of satisfaction to Dana that he was able to correct the errors of Wilkes' map, even though it necessitated a visit to Kilauea in 1887, forty-six years later. The official report upon the Geology of the Expedition was published in 1849.

Dana first saw the volcano in November, 1840, two months before Wilkes went there, and six months after the eruption. He spent five days in traveling from Kealakekua to Hilo, two nights and a day at Kilauea. The great lake, 1,500 feet long and 1,000 wide, was then in full ebullition over its surface, and there were two smaller lakes. Everything was quiet. "Instead of a sea of molten lava 'rolling to and fro its fiery surge and flaming billows,' the only signs of action were in three spots of a blood-red color which were in feeble but constant agitation, like that of a caldron in ebullition. Fiery jets were playing over the surface of the three lakes; but it was merely quiet boiling, for not a whisper was heard from the depths. And in harmony with the stillness of the scene, white vapors rose in fleecy wreaths from the pools into a broad canopy of clouds not unlike the snowy heaps that lie near the horizon on a clear day, though changing rapidly in shape through constant accessions of cloud material from below. When on the verge of the lower pit, a half-smothered, gurgling sound was all that could be heard. Occasionally a re-

port like musketry came from the depths; then all was still again, except the stifled mutterings of the boiling lakes."

In the night the surface sparkled all over with shifting points of dazzling light like a "net work of lightning." The smaller pools on the southeast side tossed up jets much like the larger, even to the height of forty or fifty feet. Streams of lava, a day later, boiled over from the lake. Upon the black ledge there were streams of hardened lava, some twisted into ropy lines or reaching out in rounded knobs, which testified to the presence of lava-floods much earlier than the recent eruption. Among the chasms he heard a few long-continued rumbling sounds, showing that a down plunging of the walls was still in progress.

The shining, glassy scoriaceous crust crushed under foot is the scum or frothy part of the boiling lakes. The Pele's hair was spun from the jets of liquid lava thrown up by the boiling process. The winds carried away the capillary threads, the heavy or loaded end going down first. The first view entertained was that the wind drew out the glassy hairs; but it was shown later by Dutton that the threads are drawn out earlier. The projected lava is divided into a succession of clots, the hairs are spun as the pieces pull apart and the wind later transports them.

Dana at this visit recognized the growth of cones from the solidification of lava about the edges of the pools. To the east of the lakes there stood a singular sphere of lava like a petrified fountain. "A column of hardened lava drops had been raised on a rudely shaped conical base, having a height in all of about forty feet. It had been formed over a small vent, out of which the liquid rock was shot up in driblets and small. jets—making one of the fantastic driblet cones, as the author has since called them—the result of blowing-hole action." These are spiracles as defined by Scrope.

The surface of the great lake was bordered by banks fifteen to twenty feet high. Dana got the impression of a very quiet action. It seemed as if a copious stream came to the surface for a moment and then flowed on. Combined with this the natural opposition to the statements of what seemed exaggerated tales of violence, led him to deny to a large extent the presence of explosive action. Kilauea was the type of quiet volcanic action. Explosive action pertained to other volcanoes like Vesuvius.

The following is an abstract of the conclusions reached in the official report. First those relating to Kilauea.

1. No cinder cones were present because the jets did not rise high enough to allow the accumulation of fragments.

2. The action was markedly quiet. The amount of lava discharged in 1840 was about half of that thrown out in 1823.

3. The lava finds an exit through rents in the ledges low down.

4. A pit four hundred to five hundred feet deep was formed at the time of eruption (in 1832 and 1840).

5. There were three great eruptions in seventeen years, with intervals of nine years and eight years.

6. There have been discharges from the walls of the pit as well as at the bottom. The pools rise and fall independently of each other.

7. The lavas are principally glassy scoriae; no true pumice; ferruginous stalactites formed by the action of steam on the roofs of caves. Minerals are sulphur, gypsum, iron alum, copper sulphate, sal-ammoniac and gases. Olivine is frequent and must have come from below in the solid form.

8. There is an unceasing current to the southwest, a part of a boiling movement. The temperature of the molten lava probably 1,900 degrees Fah.

9. Kilauea is not a solfatara, though the sulphur banks (near the Volcano House) may be so regarded.

General conclusions concerning both volcanoes.

1. Absence of cinder cones.

2. Eruptions are quiet.

3. Mauna Loa and Kilauea are isolated; there is no sympathy in their eruptions, so that no action like that of a syphon can be predicated.

4. The eruptions require water, which is supplied by the accumulations at the surface.

5. These volcanoes are not safety valves.

6. The volcanic action is simply an overflow of a liquid which accumulates till it exerts a pressure adequate to force discharges through weak walls. It is a change from a quiet flow to great activity upon the mountain's side. There is no good evidence to prove that water reaches to the central fire of the earth's interior.

7. The kinds of crater are (a) lava cones, (b) cinder scoria cones, (c) tufa cones, (d) pit craters.

8. Kilauea and ten of the Mount Loa cones are pit craters, the results of subsidence. The formation of the pits, or places of ejection of fire, have been from the northwest to the southeast.

The two kinds of lava were noticed, the pahoehoe and aa, and the latter were called "clinkers" which were represented as ordinary lava ceasing to move through cooling, and then stimulated to activity by a fresh ejection which broke up the original stream

and forced the fragments forwards; compared also to the breaking up of ice in rivers. The slope of this land from Kilauea to Nanawale was stated to be 1° 28′ or one hundred and thirty-five feet to the mile, and the average slope of Mauna Loa 6° 30′.

THE REGION OF THE DISCHARGE OF 1840 AS DESCRIBED BY WILKES.

Captain Wilkes went over the ground traversed by this eruption January 18th to 23d, 1841, and published a map of the region. He used the name of Lua Pele for Kilauea iki. A short distance from this he observed a deep crevice about four feet wide, extending in a southerly direction. At two miles he passed the *pit-crater* Kalanokano. This new term he explains as a crater "of which there is no appearance whatever until one is close upon it, and which never throws out lava." It might have been formed by the undermining of the part beneath them, as by a stream of lava, which running away had left large cavities without any adequate support, and the superincumbent rock would fall down. Some of these pit-craters are from eight hundred to 1,000 feet deep. The other craters he describes as hills of scoria and ashes formed by the ejection of lava, and gives them the name of *cone-crater*.

The first cone-crater met with is about a mile beyond Kalanokano, called Puukehula, about eight hundred feet high above the plain. From its summit eight pit craters were visible; four on the Kilauea side, one at the foot of Puukehulu, and three others to the east-southeast with two cone craters Moka-opuhi and Kanemuokama. The pit crater Alealea-iki, at the foot of Puukehulu is about five hundred feet deep, and shows that a stream of lava has flowed into it. Kanemuokama is the largest of all the pit craters except Kilauea, and an old crater adjacent the most regular of any that the exploring party had seen upon the island. The new eruptions on both sides of Moka-opuhi appeared simultaneously upon May 31st.

For several miles the country consists of rough lava clinkers overgrown with grass and stunted shrubbery, where walking proved to be irksome and dangerous. About thirteen miles southeast from the new opening is the cone-crater of Kalalua of the altitude of 1,100 feet above the plain. It has sent forth streams of pahoehoe. At the altitude of 1,244 feet, twenty-seven miles from Kilauea, twenty-one from the first outbreak and twelve from the seashore at Nanawale, is situated the commencement of the final outbreak. It began in a point, gradually enlarging, and in two miles became a torrent of fluid rock from ten to fifteen feet

thick, sweeping everything before it. The fallen timber still remained, only holes were left to show where it once stood, the stumps having been entirely consumed, sometimes reaching a depth of twelve to fifteen feet. In some places lava was found adhering to the leaves and branches of trees. A copse of bamboo remained in the midst of the flow, and many of the trees were still living. Some large trees not more than twenty feet from the stream were scarcely affected, while it was still possible to light walking sticks two feet below the surface and only thirty yards from these living trees. This was eight months after the eruption. Nearer the sea all the foliage to the distance of three hundred and fifty yards from the lava stream was killed. The slope of this stream was about one hundred feet to the mile, and its velocity was estimated to be about four hundred feet an hour.

Wilkes observed many fissures along the whole line and thinks that lava must have flowed from them, as lava seems to have issued from them in some cases. Where the ground was steep, underground tunnels were apparent. The upper part of the stream consisted of pahoehoe, and much of the lower part, while somewhat suggestive of clinkers (aa), was to be compared with the slabs of ice in rivers when broken up by the force of the current. About six miles from the sea there seems to have been a simultaneous outbreak over a large area. Occasionally a "blowing cone" was seen with quantities of salts, sulphur and hot gases still issuing from it.

At the sea the lava fell over a cliff into the water for a width of three-quarters of a mile. There were three sand hills, evidently accumulated from a shower of shivered particles of lava that prevailed while the fiery cataract existed. They were one hundred and fifty and two hundred and fifty feet high when Wilkes saw them. Brigham says they were not a third as high in 1864. And in 1883 and 1899 when seen by myself, they were still smaller, because of the action of the sea. The sand originally extended about one hundred feet into the ocean. There is more olivine in this sand than is common in the lava; due probably to its higher specific gravity.

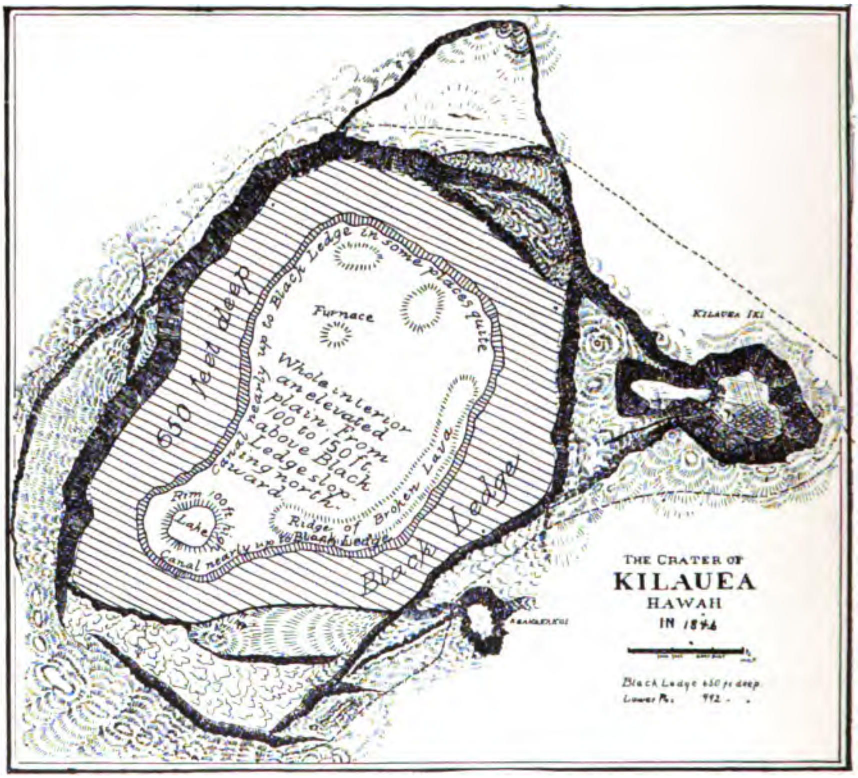
Wilkes' figure of these sand hills represents a fissure between them, but his mention of the sand storm would seem to imply an eolian origin. Dana's figure made in November, 1840, does not indicate any fissure, but in his text he calls them examples of elevations thrown up suddenly over fissures of eruption. "They consist of a rusty yellow tufa, distinctly and finely laminated." Had he not adhered to this theoretical statement down to his latest publication, it would seem as if he had himself shown the way to a

better view, for he says: "The sands are said to have been thrown out from the center of each hill while in progress; yet there was no cavity at top. As the molten lava met the sea there was a violent explosion and an ejection of fragments which fell around the center of eruption; and owing to the water which ascended and descended with them, the structure became laminated." The stratification is concentric: hence the layers were entirely of eolian origin. It is easy to contrast the structures of these sand hills with tuff cones formed near the seashore in the normal eruptive way. These always show a hollow interior. I have found these peculiar sand hills on the edge of the sea in other parts of Hawaii and Maui and believe them all to have had an eolian origin.

KILAUEA BETWEEN 1841 AND 1849.

In the interval between the discharges of 1840 and 1849 two novel features are developed. The first relates to the production of a central lava lake resting in a basin of its own cooled material. The second is concerned with the encirclement of Halemaumau by an igneous canal, coinciding nearly with the edge of the next black ledge to be formed.

In February, 1842, Mr. Coan writes: "When within four or five rods of the great lake, unaware of our near proximity to it, we saw directly before us a vast area of what we had supposed to be solid lava moving off to the right and left. We were at first a little startled, not knowing but all was about to float away beneath us, especially as the lavas for a mile back were almost insupportably hot, and gases and steam were escaping from numerous openings. On looking again, we perceived that the whole surface of the lake was from six to fifteen feet above the level of the surrounding lava, although at my last visit it was from sixty to seventy feet below. Within six feet of this embankment we could see nothing of the lake, and in order to examine it we climbed the precipice some fifty feet. The explanation of this strange condition of things is this: when the liquid contents of the lake had risen to a level with the brim there was a constant and gradual boiling over of the viscid mass, but in quantities too small to run off far. Consequently it solidified on the margin, and thus formed the high rim which confined the lavas. Twice, or at two points while we were there, the liquid flood broke through the rim and flowed off in a broad, deep channel which continued its flow until we left the volcano. The view was a new one, and thrilling beyond description."



Map of Kilauea, 1846.

In July, 1844, Mr. Coan describes a vast overflow at Halemaumau, from which rivers of lava proceeded adjacent to the black ledge on either side. The beginning of the process consisted in the welling from below of so much liquid that the outlines of Halemaumau were obliterated. The streams were described as two deep canals five to fifteen rods wide, one hundred feet deep and two miles long; it was a lake having two outlets at its opposite points, each one following the margin of the black ledge and coming within half a mile of each other under the northern wall of the caldera.

Mr. Coan had the company of his son, Titus Munson Coan, who noted the conditions already mentioned, and spoke also of a small lake upon the floor of the pit at about the middle of the west side. A diagram accompanied Mr. Coan's letter, a mere outline, but having all the essential features indicated two years later by Mr. Lyman.

There were fissures along the course of the canals, one of them two hundred feet deep, and in one place the lava plunged down a precipice of fifty feet. The character of this display was not explained at the time. In June, 1846, Mr. Coan reported that the central parts of the floor had been elevated four or five hundred feet since 1840, so that some portions of it are higher than the black ledge. Professor Dana thinks from this statement that in 1844 the lower floor was less than one hundred and forty feet deep, except along the wide canals.

The observations of Rev. C. S. Lyman in July, 1846, explain the rapid obliteration of the lower pit. See our Plate 30 restoring the condition of the caldera after the rude sketch of Mr. Lyman. He found the conditions reported by Mr. Coan. By instrumental measurements he proved that the black ledge still retained the level of six hundred and fifty feet below Uwekahuna as given by Wilkes. But there was a "canal nearly up to the black ledge, and in some places quite," encircling the pit, though in some parts obliterated. Along the inner margin of a part of the canal was a continuous ridge of angular blocks of compact lava often fifty or one hundred feet high, which Mr. Lyman considered "once constituted a talus, or accumulation of debris" on the slope of the black ledge of 1840; the floor with this margin of blocks had been elevated till this ridge overtopped the edge of the escarpement at whose incline it had been accumulated. He adds: "The phenomenon seems inexplicable on any other hypothesis than that of the bodily upheaving of the inner floor of the crater." "When visited by the Exploring Expedition of 1840, the surface of the Great Lake was between three hundred and four hundred feet below

the black ledge, and measured only a thousand by fifteen hundred feet in diameter. Consequently in six years the lake had not only increased in size, but it had actually risen in height as much as it had been previously depressed by the out-draining of lavas in the eruption of 1840. This gradual rising of the solid embankment of the lake contemporaneously with the lake itself, together with the filling up of the whole interior of the crater, is doubtless to be attributed to the combined effect of repeated overflowing together with the upheaving agency of subterranean forces." The lake at the southern end seems to have been raised upon a rim ten to twenty feet high, with the diameters of 2,000 and 2,400 feet. The lavas were in gentle ebullition, tossing up broken jets five to fifteen feet and frequently encrusted, and had a general movement southwesterly. Sticks of wood thrown into the liquid immediately disappeared, but were instantly followed by a sudden outburst of flame and smoke.

The "Furnace" marked on the map was the beginning of a dome, ten or twelve feet high with walls a foot thick, compared by a later writer to pie-crust; inactive in July but "in full blast" six weeks later in August. Brigham compares this to one of the "hornitos" described by Humboldt in the malpays of Jorullo, Mexico.

On December 7th, Mr. Coan found the lake full and active. On July, 1847, the great lake had filled up and overflowed a considerable area around its rim, and it was easy to dip up the viscid matter with sticks and ladles. Early in 1848 a thick crust formed over Halemaumau and was raised into a dome covering the whole lake. This increased in size and by August was almost high enough "to overtop the lower part of the outer wall of Kilauea and look out upon the surrounding country." This meant two hundred or three hundred feet elevation, traversed here and there by fissures through which it was possible to descry the glowing of the subterranean fires. Occasionally lava was pressed sluggishly through these apertures, rolling in heavy and irregular streams down the sides, spreading and cooling over the slopes or at the base. Thus this dome has been formed partly by upheaval and partly by igneous accretion. This is the first account of a dome over Halemaumau.

Still later in the autumn of 1848 an extraordinary inactivity prevailed throughout the crater. No fire was visible, even in the night.

ERUPTION OF 1849.

This eruption was not very important. In April and May explosions and detonations from the cones of the great dome startled travelers. They were compared to the discharge of whole ranks of musketeers or field artillery. They were repeated hourly and attended by a brilliant column of red-hot lava, rising fifty or sixty feet above the dome. "At other times red-hot stones were projected with great force into the air and sent whizzing like fiery meteors through the gloom of night." Later a stream of lava came from the ridge of the dome, flowed to the base and wound along the floor like a fiery serpent. These phenomena are what precede an eruption; and as they ceased shortly afterwards, it is presumed that the lavas escaped into some subterranean cavity, and the fires went out.

During the two years 1850 and 1851 there was very little indication of heat. Mr. Coan characterizes it as a time of "steaming stupefaction." In March, 1852, he says the great dome a mile and a half in circuit and several hundred feet high has lost its keystone and the opening is one hundred feet in diameter, increasing to two hundred in July. The lake is gradually rising and threatening to engulf the whole overhanging mass; but in the latter part of 1853 it still remained, two miles in circuit and from three hundred to six hundred feet high. The central lower platform rose during this year above the black ledge, some points of it being six hundred feet higher than after the eruption of 1840, and in some portions 200 feet above the black ledge. Lyman's ridge of blocks retained its position little changed.

The crater was "unusually dull" all through 1854. Ferns and ohelo bushes grew upon the lower platform.

ERUPTION OF 1855.

In May and June travelers reported a fiery girdle around the whole circumference of the caldera; intense heat and suffocating gases were encountered upon the road back of Uwekahuna, so that men and horses were forced to make a wide detour to the west. The fires evidently followed the course of the canals reported in 1846; and along these lines Mr. Coan could count sixty areas of fusion or "lakes of leaping lavas." One great lake was located at the foot of the path down the sloping terraces, and there were other boiling caldrons so that the continuity of the road to Halemaumau was interrupted.

On July 6th, Mr. T. M. Coan found the lava lake in the path mostly covered by a crust, but the lavas were in violent action in

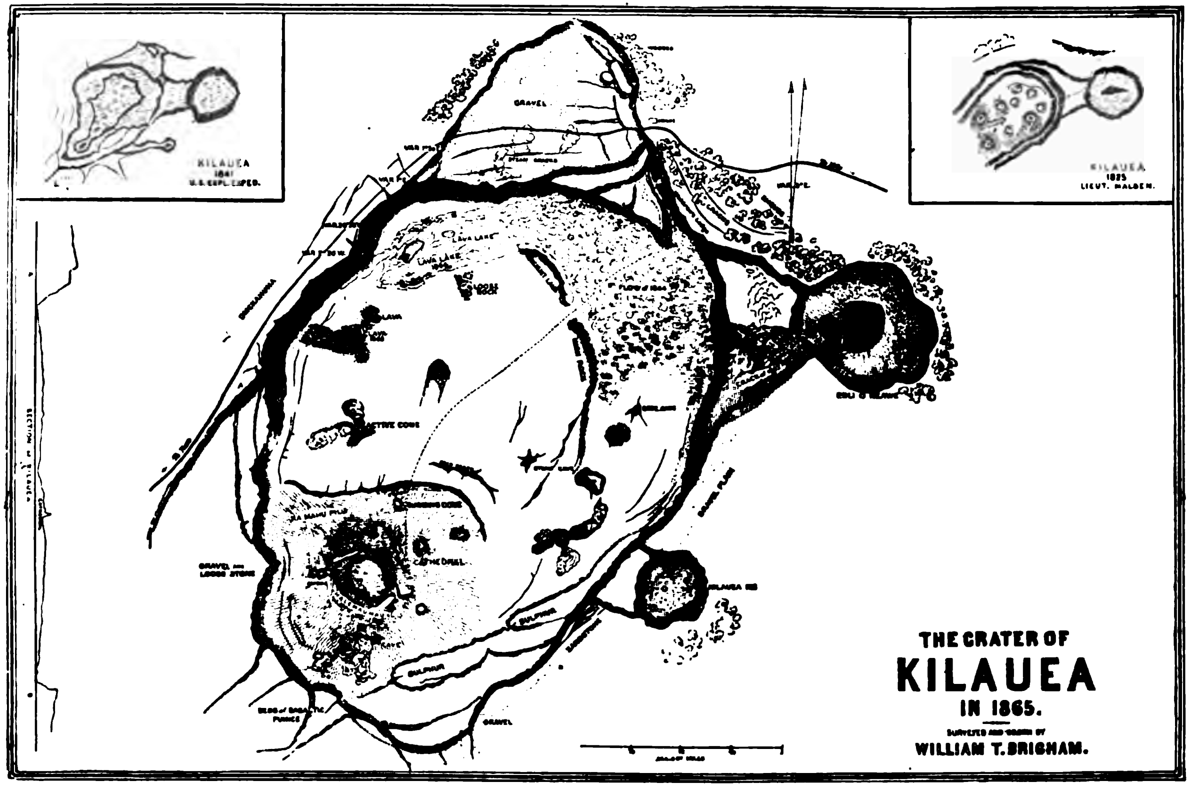
several places along the margin of the black ledge. Halemaumau was estimated to be two hundred and fifty to four hundred feet in diameter surrounded by walls seventy-five feet high. The surface became encrusted, but every five minutes there opened in the center a fiery surface perhaps fifteen feet across from which a fountain would burst out up to twenty-five or thirty feet. In the vicinity another similar fountain in a few seconds would start up and go through the same changes. There were furious surgings and outflows of lava from cavernous openings under the northeast wall. Much Pele's hair was found and there were two islands in the northwest part of the lake.

Sept. 8, 1855. Lake two or three miles in circumference, circular. Several comes emitting smoke, from some of which issued streams of lava. "One stream was not less than seventy-five or one hundred feet wide, descending at an angle of near 45° and branching off in two opposite directions. Two of these cones presented the appearance of immense furnaces." At night there was the great light of the lake and some twenty lesser lights visible.—Editorial by S. C. Damon in the *Friend*.

October 9th there was less activity and the dome had fallen in. There had been a dozen open lakes arranged in two semicircular lines from Halemaumau along the eastern and western sides, probably on the border of the lower platfom of the previous years. The flow is very distinct northwards. The encircling belt has been elevated between one hundred and two hundred feet since April.

Though meager these accounts are believed to describe the important breakdown of 1855, coinciding essentially with the great eruption from a vent high up upon Mauna Loa. It iş confirmed by the estimate of the height of Uwekahuna given by Mr. Weld in the following month.

Mr. F. G. Weld visited Kilauea November 14th, 1855, on the way to the flow of 1855, Mauna Loa. It was not a time of activity. No lake of fire could be seen, although the light of subterranean fires was obvious at night. His companion, Mr. Stuart Wortley, observed that hot stones and melted lava were occasionally ejected from small craters. And Mr. Weld on his return from Mauna Loa spoke of the floor as being evidently the cooled upper crust of fused lava. The small mounds have orifices like the mouth of a lime kiln through which one can look into the red-hot depths below. In some places there were long ridges of smoking rock fragments that had been piled confusedly upon one another. Heat and noxious gases were exhaled from various vents. The lava was generally of a dull, glossy lead color when


KILAUEA
1841
U.S. EXPL. EXPED.
KILAUEA
1825
LIEUT. MALDEN.
GRAVEL
CATHEDRAL
GRAVEL AND LOOSE STONE
SULPHUR
GRAVEL
THE CRATER OF
KILAUEA
IN 1865.
WILLIAM T. BRIGHAM.
SECTION of KILAUEA

cool; but of a brighter green or blue when more recent. The "Pele's hair" had reddish, brownish and golden hues. These gentlemen lodged in a grass hut. The height of the highest cliffs from the bottom of the pit has been estimated to be 1,500 feet, and in many places they were satisfied it was considerably less. Other familiar objects were seen by these visitors.—From *Quarterly Journal of Geological Society of London,* Vol. 13.

BETWEEN 1855 AND 1868.

In March and October, 1856, there was some sluggish lava in Halemaumau and hundreds of steam jets. The inner platform of hardened lavas keeps its elevation of about six hundred feet above its level of 1840.

J. H. Wood in 1892 says that in 1856 the crater floor was sevrael hundred feet deeper than at the time of writing. There were cones, chimneys and blow holes, and a ridge of rocks entirely gone later. The caldron was surrounded by a rim thirty feet above the crater floor and fifty feet above the lake, where the lava was surging, spouting and tossing masses from minute particles to tons in weight.

In June, 1857, Halemaumau was a lake of five hundred feet diameter surrounded by ragged walls a hundred feet high. Every three minutes a crust would form and then be broken up.

There was little change in the conditions during 1858. In August the great lake had the same size as in 1857 and there was a constant freezing of a crust alternating with fractures and melting.

In 1859 Kilauea was comparatively quiet, showing no sympathy with the great outpouring upon Mauna Loa. For several years about the same story of the comparative quiet of the central lake, the constancy of the lower platform and occasional small displays of fire is told.

Halemaumau was a lake about six hundred feet in diameter. Without it, in the basin, there was a driblet mound with pinnacles and turrets. In 1863 a large fountain played at the middle of the lake at intervals from a few seconds to half a minute, throwing up crusts of lava ten or twelve feet high, and smaller portions twenty or thirty feet high. Elsewhere it was covered by a thin crust easily ruptured by small stones thrown upon it. In October, 1863, the great lake and the black ledge were covered by fresh lavas, while the central table land five or six hundred feet above the floor of 1840 showed no change.

In 1864 Mr. W. T. Brigham commenced his examination of the volcano and its surrounding. With instruments he made an

accurate map which has been the basis of every plan published since that time. This is reproduced, as modified by Captain Dutton, in Plate 31; and from it one can learn the conditions prevalent in 1864 and 1865 and note the changes from the features described by his predecessors. Professor Dana comments freely upon these data in his book.

Some of the dimensions as measured upon this map are as follows: The main caldera is nearly three miles long; the greatest width nearly two and one-quarter miles; extreme length of the depression from north of the sulphur bank to extreme south end three and three-quarter miles; upper triangular platform near the house nearly one mile long; circumference of the main pit eight and one-half miles. The bottom of the pit is stated to be "more than four hundred feet." The observations relate to 1864, 1865, and the map surveys were made in 1865, between August 20 and 24.

The following features are distinctive: The floor is essentially upon the same level, the lower pit having been nearly obliterated by the lava overflows. The position of the margin of the black ledge is indicated by the "high rock" and "ancient lava," obviously identical with Lyman's ridge of loose blocks; by the two small lava lakes near the northwest corner, two patches of lava farther south and the active cones, one on each side of the pit. A painting by Mr. Perry in 1865, as photographed by Brigham, shows the position of the black ledge very plainly, in the slight shading; but the whole bottom was regarded as the black ledge. The sulphur banks on the southeast side of the pit are smaller than ever before. Halemaumau has its old position, and had a diameter of eight hundred feet in 1864 and 1,000 in August, 1865. It was surrounded by walls fifty feet high in 1864 and thirty feet high in 1865. Judging from the illustrations the surface of the molten lava was considerably agitated. Occasionally the liquid rose suddenly several feet and was "boiling violently and dashing against the sides, throwing the red-hot spray high over the banks." "There was no noise except the dash and sullen roar." The two small islands present in 1864 had disappeared in 1865.

Other interesting features were the "Cathedral," a driblet cone with several turrets of varying altitude, mentioned first by Mr. Coan in 1862; several caves, exhibiting the singular stalactitic tubes, and stalagmites; fissures or cracks near the northern sulphur banks, Waldron's ledge, near Keanakakoi and by Uwekahuna, all concentric with the wall of this pit; and finally one nearly a mile long rudely concentric with Halemaumau. This possibly corresponded to the border of the columnar mass outlining the

elevations in 1888 and 1892. Halemaumau was eight hundred feet long in 1864 and 1,000 in August, 1865. The encircling banks varied from fifty to thirty feet in height. The liquid was usually quiescent though occasionally in violent ebullition and throwing the spray over the bank. The small island visible in 1864 had disappeared in the following year. Distinct flames of fire were also observed. "They burst from the surface and were in tongues or wide sheets a foot long and of a bluish color, quite distinct from the lava even when white-hot; they played over the whole surface at intervals, and I thought they were more frequent after one of the periodical risings of the surface in the pit."

In 1865 Rev. O. H. Gulick presented to the landlord of the grass house which had been built for the convenience of visitors, a record book in which notes might be written descriptive of the conditions at the volcano. I have been able to examine all the records from this early date through the whole intervening period to the end of 1908; and will quote freely from them. Mention was made by Mr. Gulick of the formation of a great crack on the side of Uwekahuna from three to eight feet wide in September, 1863, following an eruption in May or June which flowed over an area of one thousand acres, and another smaller lake was formed near the north wall. There were several of these active vents in that part of the pit specially mentioned as existing in 1864 and 1865.

June 4, 1865, D. H. Hitchcock made his nineteenth visit to Kilauea and observed a lake on the north side three hundred feet long adjacent to a spiteful chimney. The older lake had been extended to the northward and lava flowed from the new lake for a mile.

June 27. C. Arnold found the lake unusually active.

In May, June and July, 1866, Mr. Coan describes a great increase in activity. New lakes and new cones opened along a curve northwest to north of Halemaumau, flooding all that portion of the caldera and reaching to the sulphur banks. The area covered was two miles long, and half a mile wide, and the usual entrance to the lake was cut off. Mr. Sessan estimated the size of the north lake as two hundred by five hundred feet. There were seven lakes between this and Halemaumau and they increased in size till the eruption of 1868. This flooded region was said by Brigham to be about fifty feet below the central area; it was a hundred feet higher than in 1865; but the central area has also risen so that the relative height was about the same. The general appearance of Kilauea had changed. The ledge of broken blocks near the margin of the earlier black ledge has nearly dis-

appeared because it has been covered by the recent outflows, and the various caves have been obliterated. Large blocks of basalt have fallen from the steep outside walls, which were speedily absorbed by the molten flood, illustrating the method by which pit-craters may be enlarged horizontally. Travelers during this summer spoke of the hissings, spoutings, rumblings and detonations as terrific. In August the activity ceased, but no subterranean discharge was noted; the central plateau remained undisturbed and hence it is not certain that an eruption took place; though the phenomena would seem to indicate a considerable disturbance.

August 6, 1866, Dr. G. P. Judd writes: "I first visited this crater in 1830 when its depth was three or four times greater than now. In 1849 I marked a spot upon the bank estimated at sixty feet above the bottom which is now out of sight." Oct. 23 he adds: "Since August 6 the long ridge of rocks and earth which had fallen from the western wall and appeared to be floating into the middle of the crater bottom, has floated past the middle to the eastward. The center is rising slowly without change of surface, while the sides of the whole crater have been overflowed and kept full of fresh lava. The action at the south lake is *grand*. There are several new lakes."

George Clark, July 20 to 25, 1867, says that on May 23, 1864, there was but one lake and that not large. At a later visit he saw a large island melt away. On the 19th inst. he first saw the large north lake, with several others. A blow-hole near the south lake had diminished in importance. Very much new lava had been flowing. The cones seen in 1864 are filled up.

Sept. 18, 1869. A. Francis Judd wrote that he first visited Kilauea in 1853. The bed has since greatly filled up and the south lake has many rivals, eight of them being now in sight.

The same day La Paz says: "Kilauea is not a crater but a deep chasm formed by the breaking of the rocks about a thousand feet below the level of the surrounding country. There never was a lava flow from Kilauea." His conclusions were based upon a comparison of Kilauea with various volcanoes in Central America. The northern lake was first formed in March, 1867, and had been enlarging ever since.

KILAUEA IN 1868.

The disturbances occurring this year have been to some extent confused with those emanating from the greater neighbor on the north. It was the time of the most extensive earthquakes known

in the history of the islands and it has not been absolutely demonstrated whether Kilauea was or was not concerned with them.

Dr. Hillebrand obtained information from Judge Kaina, an intelligent Hawaiian who resided near Kilauea during the times of disturbance. He and a Chinaman were the only persons at Kilauea at that time. From January 20th to March 27th the crater had been unusually active: there were eight lively lakes, frequently overflowing. There was a large blow hole to the northwest of the lakes which at regular intervals of a minute or less threw off large masses of vapor comparable to the discharge of steam from a locomotive. This ceased about March 17th, and the lakes became more active. March 27th the first earthquake shock was noted. March 29th Mr. Fornander found fresh incandescent lava in the bottom of the crater. April 2nd, a little after 4 P. M., the great shock occurred and great commotions throughout the districts of Hilo, Puna and Kau ensued: the ground swayed back and forth, large quantities of lava were thrown to great heights; portions of the walls of Kilauea fell in and there were fearful detonations. These continued for more than three days. "From the very first the fire began to recede." The first night it was confined to the lakes; the third night it appeared only in the south lake; and twenty-four hours later it had entirely disappeared. Two days still later came the first outburst of Kahuku. April 2d Kilauea iki was overflowed by a black shiny lava, which adhered to the trees and shrubs in the upper part of its course as shown in Plate 23.

Dr. Hillebrand visited the locality where the lava from Kilauea came to the surface, April 20th. Near the fork where the road turns to Puna instead of continuing on to Kilauea (Halfway House), heavy clouds of white vapor were seen to rise on the lower side of the road. Half an hour's ride brought the party to deep crevasses in the pahoehoe—the longest one twenty-four feet wide with no bottom visible. It was followed for four hundred feet, but with less width, never less than eight feet. In a belt about six hundred feet wide parallel with the first were a number of smaller fissures. From many of these openings hot steam issued. Fire was not visible, but it would appear by reflection at night and was probably the cause of the supposed fire seen for several days.

Judge Kaina is quoted in the Record Book as saying that by April 5 the fire disappeared and was not seen again till May 27. Since then the depression has been filling up.

July 26 W. D. Alexander says: "No material change has taken place since the visit of Dr. Hillebrand, April 18. Nearly

the whole of the pit in the southwest end of the crater is in a state of fusion. It is nearly divided in two by a ridge of rocks. The farther one of the two has about the same position as the old South lake. Nine caves, five on the south and four on the north side were spouting fiercely, while at the eastern end a small lake spouted thirty or forty feet high, forming a large cone out of the falling fragments. About the center of the farther lake lava was flowing in a southeast direction. Streams from the cones took the same direction. The eastern boundary of the pit seems to coincide with a great crack formerly existing and delineated upon Mr. Brigham's map. The display of fireworks tonight was magnificent and shows increasing activity.

Aug. 5 the South lake was the center of operation.

Aug. 7 W. W. Hall says: "There was very little action but there were eight or nine blowholes making a great noise, and fire was visible in some of them. The activity was less than in July."

Sept. 5, C. E. Stackpole says: "There were twelve lakes in active operation just before April 2. Nearly the whole of the north part of this pit was thus covered with liquid lava. For two weeks after the earthquake there was no fire, but it has now returned."

Mr. Coan was quite successful in his search for a discharge of the lava in August. After passing several smoking fissures he turned to the left, towards the sea, and after an hour's hard search among rough hills discovered five different points on a line of less than a mile in length where fused lavas had been thrown out. The largest patch was 1,000 feet long and six hundred wide, with an average depth of ten feet, upon whose surface tumulated eminences were still steaming, and is represented upon Plate 26, near the Halfway House. This locality is about eleven miles S. W. from Kilauea. The facts discovered by Mr. Coan and their connection with Kilauea are acceptible; but his theoretical view that these lavas continued underground to connect with the discharge at Kahuku is open to serious objections.

Mr. E. D. Baldwin has investigated the country to the south of the Halfway House, and has kindly furnished the following statement: The reader will note that there is a series of cracks to the south of the Half-way House from which the considerable area of lava southwest from the 1823 flow exuded. This was not seen by Mr. Coan. The area as figured may include a little more lava than belongs to it. The eastern finger-like protuberance must have been part of an older flow: but the flow is believed to have included most of the area marked '68 crack.

LETTER FROM E. D. BALDWIN.

I believe you asked about the flow from the 1868 crack! Would say that in my survey, we camped about two weeks, a mile below where the main flow left the crack; our camp being located mauka of Puu Nahaha, an old fault line, just two miles opposite the Kapapala Ranch houses. Just back of the Halfway House, the lava made two large spurts; the upper one welling up through the crack and covering probably three acres; about one-half mile below this, the lava spurted up through the crack and ran for several hundred feet, then it seems to have run under ground, until it reached the point mentioned above, about a mile above our camp, where the whole appearance of the flow, is that of a sudden opening of the crack along its whole line, and the lava flowing out in a great belch, twenty or thirty feet high, and rushing towards the sea, mostly along the line of the crack. A portion of the flow turned off towards the 1823 flow, striking several old red cones, in its path, and completely plastering the upper side of these cones with new black lava. One old red cone especially was very noticeable, it stood right in the line of the rush of the lava, which struck the upper side, and poured over the upper rim and through the old crater in the same, leaving the lower side of this cone untouched; as the high rush of lava passed on, it subsided leaving this cone standing at least thirty feet high, with its upper side completely plastered with a layer from one inch to a few inches in thickness, and at the foot of all of the cones, immense grooves in the new lava show the force of the rush of lava as it subsided. I climbed to the top of the cone, and it seemed fully forty feet high on its upper side and highest part where the lava had just reached and splashed over; on both sides of this highest point, the lava had rushed over and through the crater, breaking away its lowest wall on the southwest side. I made several trips to where the main flow first left the crack, and there is no question whatever about its coming from the crack at the time it opened in 1868, as just above this point is an old red aa flow, and all the lava around is the same. Also from this point and all along the crack for miles down the lava spurted into the air, leaving many lava spatters, sometimes several hundred feet from the crack, looking more like our old mud pies, we used to make when boys. These lava spatters are of the same age and nature as the flow; also the flow can be traced all along, in many places, running back into the crack. The depth of the flow is on an average of one and one-half feet, and in many places looks like paving it is so smooth. Where the flow struck the forest in its line, it is full of tree moulds, many of which stand several feet high; and were so

suddenly formed that they are all capped over with lava on top.

Judge F. S. Lyman of Hilo, was living at Kau, between the Pahala Mill and the 1868 mud flow, at the time of the great 1868 earthquake, and states that all he remembers, is that they saw a great many lights in this direction, the night after the great earthquake, but so upset and taken up were they by the terrific shaking they got, and subsequent Kahuku flow, from Mauna Loa, that no one paid any attention further to the region of the great crack. My opinion is, that the flow from the 1868 crack, was of only a few hours duration, also the whole line of this flow is completely hidden from the Kapapala Ranch houses, as well as from Pahala, by the Puu Nahaha fault line, and Puu Ula hills, also intervening forest, so that the lights seen by Mr. Lyman, must have been reflections from the glow holes along the line of flow.

THE CHANGES IN THE PIT.

Returning to Kilauea, Dr. Hillebrand states that on the 18th and 19th of April, the crater was entirely devoid of liquid lava. Large segments of the walls had fallen in on the west and eastern sides. The heat was considerable in the pit of Halemaumau, too great for the hand to bear. This pit was more than five hundred feet deep. More than two-thirds of the old floor of Kilauea has caved in and sunk from one hundred to three hundred feet below the level of the remaining floor, the submergence having been most prominent in the western half. There was a depression from Halemaumau northwesterly, when a cliff three hundred feet high loomed through the mist. Surmounting this, Dr. Hillebrand found himself at the brink of a fearful chasm several hundred feet deep, and about half a mile long from south to north. Very hot air rose from it. Changes in the floor were taking place constantly.

Mr. Coan thus describes the same area as seen in August:

"The central area of the great crater had subsided about three hundred feet, forming a new 'Black Ledge' of unequal width all around the crater. In some parts the central depression left the ledge a perpendicular or beetling wall with a serrated line, but in most parts the center sagged away gently, forming a large concave basin with an angle of twenty to seventy degrees. The surface of this concave was once the crowning or convex portion of the crater, where ferns and ohelo bushes had been growing for nearly twenty years. The superincumbent plateau has been depressed so quietly that the surface is very little disturbed, and the ferns and ohelo bushes are still growing in the basin three hundred feet below their position on the first of April. Some

parts, however, of this great area have been covered with fresh lava, and some ferns have been killed by heat and gases.

"From the Black Ledge I passed down and across this depression (about a mile) and then up the ascent on the other side for half a mile to the rim of Halemaumau. This is all changed; it has gone down some five hundred feet below the highest point on the Black Ledge, and about two hundred feet below the depression in the basin above mentioned. The walls have fallen on all sides, and the pit resembles a vast funnel, half a mile in dameter at the top and about 1,500 feet across the bottom. There are two places where visitors can descend into this great pit, with some difficulty and risk. Much of the time, this pit is filled with smoke and sulphurous gases, with little visible fire; occasionally, however, detonations and fiery demonstrations occur in this awful pit."

By comparing maps and notes it is possible to outline the area and dimensions of the lower pit created by the breakdown of April 2-5. More than two-thirds of the floor had collapsed, coinciding approximately with the canals of Lyman, the ridges of Brigham, and later with the depression mapped by Lydgate in 1874, an area of 8,000 feet long, 6,000 feet wide in the northeastern portion, narrowing to 3,000 feet at Halemaumau. The depth was greatest at the southern end, six hundred feet, half as much in the middle with sloping walls. The comparison of the basin to a heavy pie crust, "fallen in at the middle, leaving a part of the circumference bent down but clinging at the outside of the dish," well describes its appearance. Compared with the breakdown of 1840 it will be seen that the lava removed must have been about the same. The black ledge had increased somewhat in altitude between the two dates, at least fifty, perhaps one hundred, feet. The task now set before the volcano for the next eighteen years, 1868-1886, is first to rebuild the mound of Halemaumau to a level with the black ledge, and then the filling of the basin so as to cover the entire floor.

It is stated by Mr. Nordhoff that just before the earthquake of April 2d, streams of lava oozed out through the crevices in the depressed area between Kilauea and Kilauea iki. The evidence of a lava flow is afforded by the adherence of lava to the trees, perhaps fifteen feet above the original surface. These were visible in 1886, and a photographic representation of the trees thus encrusted is presented in Plate 32. These incrustations may have been only a few clots thrown out from the opening.

The line of the fissure near Kilauea iki runs N. 60° W. by compass in 1905. Between one and two hundred feet above the

floor is a wide fissure lined with clinker or scoria, very fresh, of both bright red and black colors, the same material constituting the driblet cones. From this fissure there was a discharge of a considerable stream of ordinary aa and pahoehoe down to the lowest level through the forest. It is easy to distinguish between the flows of 1832 and 1868 by the presence of some vegetation on the earlier discharge. The specimens of clinkers are very much like those seen in the rent at Kahuku which came out at the same time, except that the latter contain a considerable green olivine.

KILAUEA FROM 1868 TO 1879.

After the great disturbance of 1868, the volcano seemed to take a rest.

Nov. 6, 1868. D. H. Hitchcock wrote that a chain of lakes had formed around the pit. Since the earthquake the whole central part had sunken three hundred feet. The greater part of Halemaumau had fallen into the South lake, which is more than five times larger than in December, 1867. The high ridge of rocks has disappeared. The fire is entirely confined to the South lake. The center of the pit is now lower than the South lake, and will evidently receive the lavas flowing from the higher level. The great chasm about the border was not found till several days after the earthquake. For three weeks the action at the South lake has been increasing. It was two hundred and fifty feet deep at first, and is now only one hundred feet deep and it continued to fill for three weeks longer (Nov. 26). Four earthquake shocks were also noted at this time.

In July, 1869, Mr. Coan states that the great lake was so cool on the surface that he was able to measure its dimensions without difficulty. It was five-sixths of a mile wide at the bottom four hundred feet below the rim, and more than a mile in length from north to south at the top. The lava was still molten fifty to one hundred feet below the surface, as seen in deep fissures.

Sept. 8, 1869, Prof. J. D. Butler saw nine cones in the south lake.

Sept. 13, George Jones of Kahuku spoke of lava flowing from these cones. There were two earthquake shocks on the 13th and five the next day.

Nov. 9 Kilauea was visited by H. Bingham 2d. He mentions the South lake, North lake and a third in the southeast section of the pit. There was no visible flowing lava, but stones thrown into the chasms from seventy-five to one hundred feet down splashed into a liquid mass.

Jan. 10, 1870. D. H. Hitchcock reports the South lake nearly solid with a little fire. The center of the pit seems to be sinking, and is below the level of the South lake. Pele has not yet recovered from the effects of the agitation of 1868.

Feb. 2. Kilauea very active; several lakes opened. Mrs. S. J. Lyman.

Judge Kaina is quoted as saying that the south lake overflowed on Feb. 19, 1870, for the first time since 1868, and ran mauka for fifty feet. March 6 the flow was rather quiet.

March 28. South lake filled up. It is one level mass beneath which fire is visible.

April 26-28. D. H. Hitchcock reports the filling up of South lake ,around which a mound is forming. Lava is flowing into the deep basin northward.

June 4. Crater quite lively. Ten cones in action.

July 22. Fresh lava from which impressions of coins were obtained.

Aug. 22. Crater rather inactive. J. H. Coney.

Oct. 5. Noise like report of cannon. One lake formed where there had been three. Of these the South lake was the largest. Severe earthquake coincident. There was boiling and surging for five minutes after which quietness ensued. Lakes not well shown because they were so low down.

March 20-29, 1871. Dense clouds; no fire except deep down in crevices.

April 13. Halemaumau being built up, forming a dome as in 1857. General level of South lake about up to that of the main crater. Little fire but dense smoke. D. H. Hitchcock.

July 6. Nothing but smoke to be seen. E. Bailey.

Sept. 13. No fire. Miss M. A. Chamberlain.

In 1871, Mr. Coan says there had been discharges that filled the central basin to the depth of fifty feet and also flowed two miles northerly since his report of 1869. In August Halemaumau had again become empty, but a year later it was full again and discharged into the basin of 1868.

Jan. 11, 1872. D. H. Hitchcock says that the main pit has been overflowed from the South lake, a descent of two hundred and fifty feet. There are three larger cones in this lake, which are about seventy-five feet lower than the summit of Halemaumau. There are deep pits with these lakes. Fire is being concentrated in the vicinity of where the South lake has been.

March 1, 1872. Kilauea visited by Clarence King and A. Hague. King says: "A fluid stream of basalt overflowed from the molten lake at the south end of the crater and flowed north-

ward along the level basaltic floor of the pit. Numerous little branchlets spurted from the sides of the flow * * * and then congealed. I repeatedly broke these small branch streams and examined their section. In every case the bottom of the flow was thickly crowded with triclinic feldspars and augites; while the whole upper flow was nearly pure isotropic and acid glass." Charles Darwin had previously made a similar statement about the development of minerals in the lower portions of volcanic flows.

March 20. J. Kavanagh. Quiet for six months. Four fissures have opened in which there is fire, which occasionally spurts out.

April 26. F. C. Autridge. Seven cones pouring forth smoke; their interior a vast gulf of fire. Stalactites hang from the roof of the dome.

Aug. 4. Visit of Samuel Kneeland. Feels rewarded for the exertions made to come so far, the volcano being moderately active.

August, 1872. A year earlier Halemaumau was a deep cavity, but had filled up and is now overflowing into the basin of 1868. T. Coan.

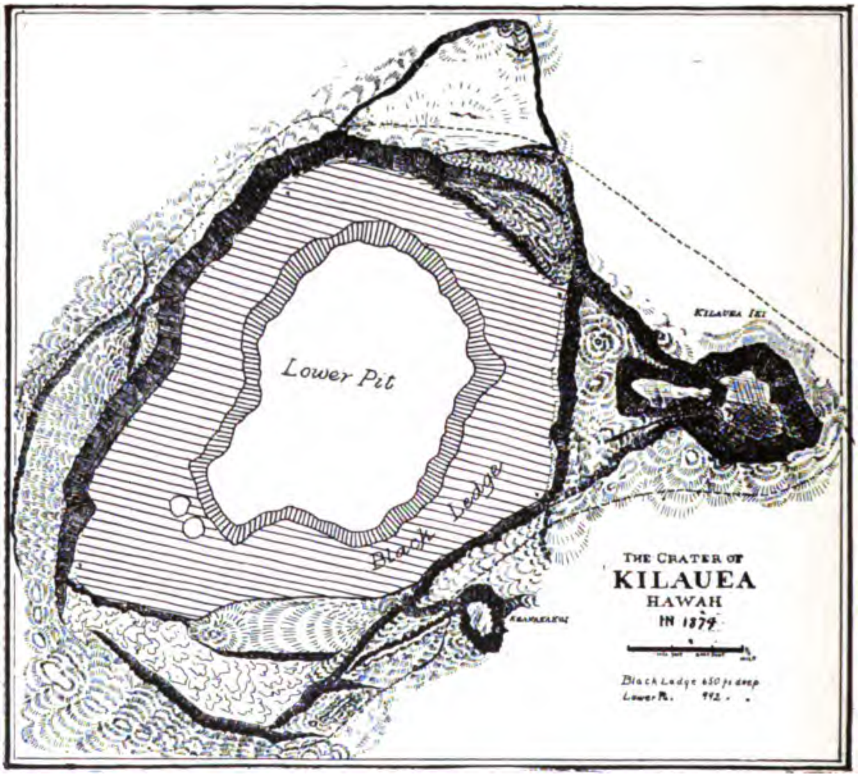
Oct. 21. D. H. Hitchcock says Halemaumau is like what it was from 1845 to 1868, an immense dome six hundred feet higher than the center of the pit, equalling in altitude the bordering black ledges. On its summit are the two lakes from which lava streams down in various directions. Nothing is left of the high banks surrounding the old south lake.

Nov. 26. W. P. Ragsdale says lava has been flowing to the foot of the west bank, (Uwekahuna), and is now proceeding from the south lake in a covered canal towards the north end. Pours over the bank in a cataract of fire.

Dec. 11-16. Grand flows; unusually fine.

March 3d, 1873, Mr. Nordhoff reports that the great lake had been divided by a low ledge of lava into two parts; each body having a diameter of five hundred feet, circular, separated by a low lying ridge, and the two together surrounded by a wall eighty feet high. The surface of the first lake had a gray color. Molten lava was repelled from the borders to the center, then flinging aloft fiery waves as much as thirty feet, followed by a hissing sound. Fiery rings were constantly being pushed towards the center, piling up lava fifteen feet above the general level. The second lake was agitated more violently, spending its fury upon the southern bank. The cliff was undermined for one hundred and fifty feet from which the waves were repelled with a dull heavy roar. The word terrible best represented the character of

PLATE 33.



Map of Kilauea, 1874.

the agitation. The heat back of the bank was almost insupportable: a hot draught came from the cracks behind, charged with sulphur. Still farther back were several cones. These commenced as small vents through which lava is ejected and by a secretion built up pipes twenty to thirty feet long, open at the top and ruined by violent explosions. Inside was the molten lava, and stalactites yet in the formative stage waved in the wind. The cooled surface was extremely thin.

In January, 1874, Miss Isabella L. Bird, represented that the lake had an irregular shape five hundred feet long, divided in two, with banks thirty-five to forty feet high. June 4th the rock about the lake has risen much, and the precipitous walls were thought to be eighty feet high. Six hundred feet from the lake there was a blowing cone, like a beehive, twelve feet high, forty feet deep inside, with walls two feet thick. It was throwing up jets and clots of lava with a deafening roar and subterranean noises. Halemaumau was on a hilltop. Eleven fire fountains danced around the lake, half of them combining into one thirty feet high at the center. A cone lower down discharged lava intermittently. The same month, Mr. J. M. Lydgate presented a rough sketch of the caldera to the Government Survey, from which is derived the restoration presented in Plate 33. The two lakes of the previous observers appear—and the area of the lower pit formed in 1868 well shown. The black ledge was quite extensive and probably at the same level as in 1868.

July 8. D. H. Hitchcock says the crater is filling up with fresh lava, but the floor is sinking more and more as a whole. Halemaumau has half the height of the lower or southern lake. Two earthquake shocks were recorded for July 10.

Sept. 3. R. Whitman and B. F. Dillingham saw the south lake moderately active.

Sept. 10. Lava broke through the crust in the eastern edge of the basin and flowed rapidly westward, spreading over several acres. It was all done in two hours. C. E. Stackpole.

Early in October Mr. Coan states that the lower pit of 1868 had been filled up about two hundred feet, and the mass about Halemaumau had "become a tumulated elevation nearly as high as the southern brim of the crater." In December Mr. J. W. Nicols of the British Transit of Venus Expedition reports several important features. There were four lava lakes, the largest six hundred feet long, in which seven or eight fountains were playing near the edges. One of the lakes filled to the brim, while the others were surrounded by walls. The cone about the whole area was about seventy feet high.

Dec. 8, 1874. H. M. Whitney draws a rough plan of the lakes with a new nomenclature, which was adhered to for some time. The more southern lake was called Halemaumau, three hundred feet across. Eight hundred feet to the north was Lake Kilauea, five to six hundred feet long and three hundred across. The larger diameter of the depression was about five hundred feet. Adjacent to Halemaumau there had been a third lake, active two years earlier, but now closed up. The height of the north wall was one hundred and twenty feet.

Feb. 2, 1875. F. J. Scott draws a similar plan, and witnessed a great gush from Lake Kilauea.

Feb. 19. W .D. Alexander saw action in Lakes Halemaumau and Kilauea.

Feb. 26. Prof. Joseph Moore of Richmond, Indiana, said that Halemaumau was full and overflowing: and there were four lakes in action.

Aug. 7. There were two severe earthquake shocks.

A party from the English Challenger Expedition report the lakes Halemaumau and Kilauea as unusually active. There were five jets playing in the first, and the same number of inferior importance in the second. The lava rose and then subsided in the first. A small cone between the two blows jets of lava from thirty-five to forty feet. A lava cascade poured to the northeast of the second lake. Spectroscopic observations gave a continuous spectrum, the red being the brightest and an occasional flame in the green. Magnetic observations proved the presence of considerable iron.

Sept. 3. More active than for a long time.

Sept. 6. W. M. Gibson writes that Lake Kilauea had risen about ninety feet. Streams flowed from Halemaumau and Kilauea-iki into Lake Kilauea; also to the southeast. He could see from the Volcano House lava jets leaping above the banks; so that the lava must have risen a hundred feet during his visit.

Jan. 14, 1876. Lake Kilauea sent forth a broad stream into the caldera for four hours.

Feb. 22. Both lakes in full activity. A. O. Forbes.

April 20. Cascade of lava into a pit seventy-five feet to the south of lake. River from below cliff; both streams of short duration.

May 2. D. H. Hitchcock. Halemaumau has built itself up two hundred feet in one year. Lava from the south lake has almost filled up the great central depression. Six streams running down Halemaumau all night.

July 9. Lava streams running four miles per hour. T. K. Noble.

Aug. 25. E. H. Butler of Hobart, Tasmania, and others. Lakes full to overflowing, covering fifty acres on the west side. Waves of fire continually leaping twenty-five feet intó the air.

Jan. 1, 1877. W. P. Toler compares present conditions with those prevailing in 1843 and 1845. Then the bottom was four hundred feet lower than it is now. Then the lake was ten to fifteen feet below its banks; now it is depressed for two hundred feet in a cone that is one hundred and eighty feet high. Then the activity was in the lakes; now the lava flows over a hardened surface. Then there was only one lake; now there is a depression of two hundred feet where a second one has existed, though now extinct. Much rock has fallen from the high cliffs. He can now read newspapers by the light of the fires, upon the north bank.

May 4. Large party found "more activity than has been seen since 1868." Nineteen earthquake shocks during the evening. Plenty of subterranean fire and some flowing lava.

May 6. S. B. Dole reports the formation of a fissure extending from the floor through the bank and into the woods beyond, just before his arrival. Lava spouted from this crevice fifty to one hundred and fifty feet into the air. Halemaumau drained. Estimated depth of hole at two hundred and fifty feet.

May 8. H. M. Whitney finds this opening and gathered tresses of Pele's hair twenty inches long.

May 21. T. E. Cook found a place one and a half miles southeast from the Volcano House, where lava had come out of a crevice some two hundred feet below the top. These last three observations may point to Keanakakoi. Pea Wilkes, with his father, witnessed an eruption at Keanakakoi in 1877, which may be the same with that mentioned by Mr. Cook. The whole floor was a bubbling, boiling mass sending surges from side to side. The heat was so great that they could approach it only on the windward side.

Aug. 2. Lava rose thirty-five feet in the south lake in a few days.

Sept. 4. E. O. Hall thinks the floor is five hundred to six hundred feet higher than in 1837.

Sept. 8. Bottom of South lake fell fifty feet. W. H. Lentz.

Oct. 2. Crater active. H. M. Whitney.

Oct. 9. Rev. W. P. Alexander says: "I visited this volcano forty-five years ago. It was much more active then than now."

Dec. 21. Overflow witnessed. Fountains on the north side of Halemaumau three days later.

Jan. 1, 1878. Volcano very active. W. H. Lentz.

Jan. 18. Curtis J. Lyons calculated altitudes with an aneroid barometer. Foot of the road down to the crater and level of Halemaumau five hundred and three hundred and fifty feet below Volcano House. Height of Uwekehuna six hundred and fifty feet above its base. Halemaumau four hundred feet long, one hundred feet wide. Lake Kilauea not approachable. Extensive flows of lava from it on the north side running N. N. E. for three-fourths of a mile. Present height of cone estimated at one hundred and seventy-five feet.

June 8. Two flows between the old north and the present south lake.

June 28. Rev. L. H. Hallock. "A surging mass of lava, dashing like surf against the walls of Halemaumau and throwing gory clots high over the ledges, with Pele's hair streaming in the whiffs of rising gas, accompanied by a roaring like that of the sea, was the never-to-be-forgotten experience of our day at the volcano."

Sept. 20. J. Mott Smith. "In my former visits, 1851, 1856, 1862, I saw no display of fire to compare with what is now seen. The floor of crater much changed and elevated. Whole floor is in constant motion rising and subsiding by turns."

Nov. 24. Very active; lava within twelve feet of the top of the bank.

Jan. 7, 1879. H. M. Whitney. Two lakes now as formerly, lava nearly up to the brim but not overflowing; lava breaks out on the sides and fills up the center. By night fires seen in every part of the crater. Some parts of the hill surrounding south lake as high as the south wall of Kilauea.

Jan. 8. Wm. Gardner. South lake with lava fifty feet below the rim and boiling like water.

There was at this time one large lake enclosed by a crag wall twenty feet above the fire. These crags increased till April, becoming four hundred and fifty feet high. Fire now less than forty feet from the top. Lentz said to have counted three hundred and seventeen different points from which fire was bursting at one time. Reported by Miss C. F. Gordon Cumming.

The eruption came April 21. The bottom dropped out on this date. W. H. Lentz.

Dr. Coan, in a letter of June 20, said that the lake, which had been overflowing its banks and whose rim had been raised till it was nearly as high as the outer wall, was suddenly emptied by an

underground discharge and subsided several hundred feet, leaving nothing but a "smoking basin."

April 28. Almost extinct; some vapors. A. O. Forbes.

The fire returned very soon. June 24 W. H. Lentz states that both lakes were active; jets of lava, appearing like a fountain of fire from the Volcano House were thrown up. William Tregloan writes that on July 2d the two lakes had become one, of enormous size, throwing lava to the height of fifty feet. July 14, Lentz reports a flow of lava extending over one-eighth of the entire bottom. The sulphur banks on the southeast side caught fire. A large part of the bank of south lake fell in. The bottom of Keanakakoi is covered by a smooth black lava, very fresh looking, which is supposed to have been ejected at about this time. The faulted block let down upon the northern side of this pit must have reached its present position at an earlier date.

In October, Miss C. F. Gordon Cummings visited Kilauea. She represented that after the discharge of April 21 a wall of blocks or crags rose around Halemaumau to the height of three hundred and sixty to four hundred feet. October 27 there were fiery waves tossing over this lake. Two days later she climbed "six hundred feet" of these rough blocks and was disappointed at not seeing much liquid lava, though fire was visible in the inside cup, and fountains shot out horizontally from the base of the crags. She figures several large spiracles in the midst of the lakes.

Dec. 2. H. G. Kelley could find no flowing lava. Long sticks thrust down in crevices would ignite.

Jan. 5, 1880. T. J. Kinnear figures a lava lake on the edge of a bench with a pile of old lava below. Fire flowed in a succession of waves across the entire lake.

April 1. Crater not very active.

April 23. A. G. Low. Lava flowing to thickness of two or three feet.

May 18. J. M. Alexander saw Halemaumau four hundred feet broad throwing lava seventy-five feet high, while south lake and a new lake were forming. The path taken became impassable by fumes of vapors.

June 28. First visit of L. A. Thurston.

THE CONDITIONS OF 1880.

By May, 1880, according to Mr. Coan, Halemaumau had become a boiling lake discharging copious streams into the great central basin. In July, Professor W. T. Brigham paid another visit to the volcano. He considered that during the previous eighteen years Kilauea must have increased five per cent. in its

lateral dimensions. The floor where first trod upon was six hundred and fifty feet below the Volcano House and the central portion three hundred feet; or, in other words, the floor was raised as a flat dome three hundred and fifty feet high, which had accumulated partly by the natural building up by accretion and partly by an irregular elevation. Halemaumau had now become a regular dome surmounted by four lakes having an average diameter of 1,000 feet each. The lake of 1865 seemed to have lain in the midst of these four lakes, no one of them by itself reproduced from its progenitor. The latest one began to form May 15th and its bank was nearly on a level with the surrounding rock. The others had stratified walls, sometimes an hundred feet high, from which blocks were constantly falling because of the undermining action of the lava beneath. As seen at night these molten lavas were white hot. In earlier visits blue and green flames were observed, seldom lasting more than a few minutes. Now the flames issuing from a cluster of blow holes burned constantly with these colors, the time of continuance exceeding twelve hours. Very little steam was thrown off at this time. The southern sulphur bank had wholly disappeared, having been consumed by a fire occurring a few months earlier.

Sept. 18. The "New" lake, starting in May, increased to the circumference of 3,000 feet with sides from fifty to sixty feet high.

Sept. 25. Severe shock of earthquake. Lentz.

Oct. 27. New lake said to be one hundred and eighty to two hundred feet below top of its banks. Both lakes quite active. L. P. Tenney.

Nov. 4. W. Bolsea describes three lakes. Lava flowing on north side of Lake Kilauea crowded into very small dimensions. Halemaumau remains as it was eighteen months previous, but is inaccessible. The special seat of activity is a new lake to the southeast not far away from Halemaumau. Activity vigorous but not violent. No apparent sympathy between the two lakes.

Dec. 7. J. M. Lydgate finds Volcano House 4,021 feet above the sea by syphon barometer.

Feb. 15, 1881. Fountain of lava streamed up northwest of rough pile and spread lava over much of the floor.

Feb. 20. New lake very active.

July 20. Four lakes visited, viz., Halemaumau, New Lake, Old Lake and South Lake. New Lake specially interesting. Lava in it rose and fell twenty feet. A bright red spot appeared in the farther corner, the crust cracked, red lines of lava appeared, pieces of the crust thirty feet long sank beneath the surface and

the whole mass was boiling. W. W. Hall, Miss H. S. Norton and others.

Aug. 2. Flow of lava from New Lake. The same from Halemaumau Aug. 5.

Aug. 15. N. B. Emerson reports activity in New Lake. Fountains thirty to forty feet high; waves dashing against cliffs; tables of black lava drawn into the settling vortices.

Aug. 19. New Lake has become the "show" crater. Much the same as when last described.

Oct. 25. T. H. Davies. Surface of New Lake always agitated. Nine caldrons splashing twenty feet high. Halemaumau has more jets. A pit of fire also to the right. Considerable flow of lava.

Jan. 16, 1882. S. C. Damon had a grand view of the breaking up of New Lake.

March 7. Lakes break up both in day and night time.

March 30. Additional lava poured into lakes.

May 30. Both lakes active.

CAPTAIN DUTTON'S VISIT IN 1882.

A very complete and satisfactory account of Kilauea is that given by Captain Clarence E. Dutton in the Fourth Annual Report of the United States Geological Survey and the attempt will be made to present its most important points. He applies to the volcano with some hesitation the term *Caldera*,[43] which is equally appropriate for Mokuaweoweo, Haleakala and other Hawaiian examples. It is what Wilkes, and after him Dana, calls a pit-crater. Geikie uses caldera to signify explosion-craters and crater lakes, citing as examples Palma in the Canary Islands, Val del Bové in Etna, eleven illustrations in Ecuador, the crater-

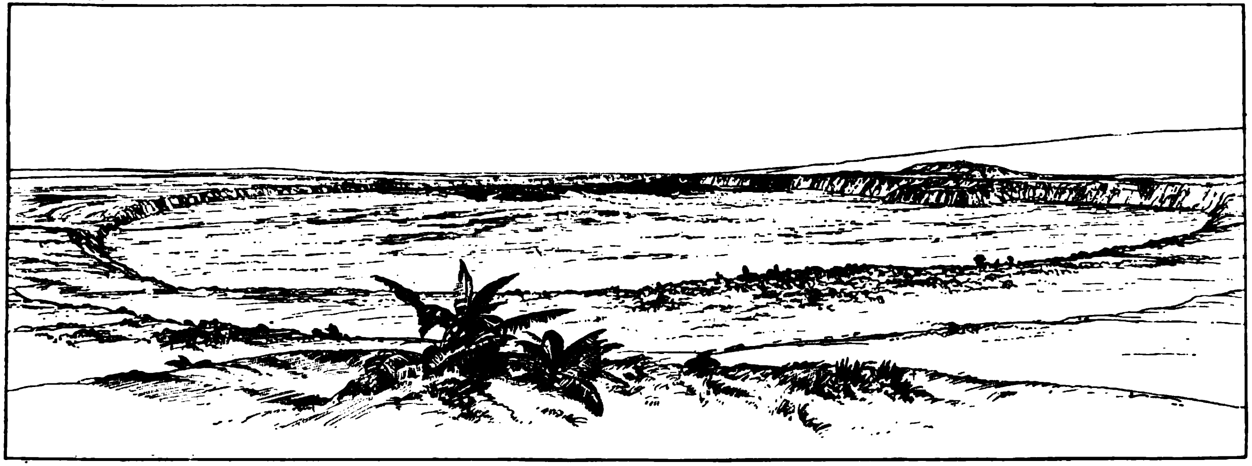
[43] On referrng to Lyell's Elements of Geology, 1865, one may learn why the term Caldera began to be used. Lyell describes the volcano upon the island of Palma called "La Caldera." Within it is a bowl-shaped cavity from three to four miles in diameter, encircled by a precipice from 1,500 to 2,000 feet high. Upon one side a breach has been effected where there is a descent of two thousand feet from the center of the Caldera to the sea. The layers of volcanic rocks dip quaquaversally outwards, usually at a small angle but in some places as much as forty degrees. Von Buch had spoken of this volcano as a cone of elevation. Lyell prefers to apply to it the theory of engulfment and speaks definitely of a Caldera as a type of volcano, to which are also referred the Val del Bovè of Etna, and one in Java, p. 621. Lyell therefore preceded Dutton in the use of the term Caldera, but both agreed as to its significance. Early authors have referred these and others to crater rings; such as the Somma about Vesuvius, Bourbon, a circle four miles in diameter, and Teneriffe. The supposed original Krakatoa belongs to this category.

lake Mazama in Oregon, and others. The origin of Kilauea is not so clearly a case of explosion as in the other cases cited. Dutton, however, does not enter into the discussion of the origin of the caldera. Plate 34 is a copy of a panorama presented in his report.

Starting from the Volcano House the path leads over a series of steps that have been faulted off from the main platform of the country. On reaching the bottom the way leads over freshly formed pahoehoe, rolling smooth-surfaced bosses, not much inclined, but at about one and three-fourths miles the slope is much steeper for about one hundred feet. Reaching the summit he came to the "New Lake," said to have appeared first in May, 1881, being about four hundred and eighty feet long and over three hundred wide, surrounded by walls fifteen to twenty feet in height.

"When we first reach it the probabilities are that the surface of the lake is coated over with a black, solidified crust, showing a rim of fire all around the edge. At numerous points at the edge of the crust jets of fire are seen spouting upwards, throwing up a spray of glowing lava drops and emitting a dull simmering sound. The heat for the time being is not intense. Now and then a fountain breaks out in the middle of the lake and boils freely for a few minutes. It then becomes quiet, but only to renew the operation at some other point. Gradually the spurting and fretting at the edges augment. A belch of lava is thrown up here and there to the height of five or six feet and falls back upon the crust. Presently, and near the edge, a cake of the crust cracks off, and one edge of it bending downwards descends beneath the lava, and the whole cake disappears, disclosing a naked surface of liquid fire. Again it coats over and turns black. This operation is repeated edgewise at some other part of the lake. Suddenly a net work of cracks shoots through the entire crust. Piece after piece of it turns its edge downward and sinks with a grand commotion, leaving the whole pool a single expanse of liquid lava. The heat is now insupportable, and for a time it is necessary to withdraw from the immediate brink. Gradually the surface darkens with the formation of a new crust, which grows blacker and blacker until the last ray of incandescence disappears. This alternation of the freezing of the surface of the lake and the break up and sinking of the crust goes on in a continuous round, with an approach to a regular period of about two hours. The interval between the break-ups varies, so far as observed, from forty minutes to two hours and a quarter. Probably the average interval is somewhat less than two hours. The explanation of the phenomenon is not difficult."

PLATE 34.



Panorama of Kilauea in 1882.

The following is an abstract of the text: Melted silicates occlude notable quantities of water and when they solidify they exclude the water just as water itself excludes air in freezing. The excluded gases are mechanically entangled as bubbles which are numerous enough to diminish the density. The first inch or two of crust which forms is cooled quickly and becomes stiff and black in a few minutes and is termed *tachylite*. Being full of vescicles and spongy it is light enough to float. Subsequent additions to its thickness are made to its under surface. These become more and more compact through the disingagement of the gases, thus increasing the specific gravity. When this has considerably increased the position is unstable, and rupture once started is quickly propagated through the entire crust, which goes to pieces and sinks.

Less than half a mile northerly is the greater lake or Halemaumau, nearly 1,000 feet long, six hundred feet wide, and five hundred and eighty feet below Uwekakuna. It is surrounded by cliffs an hundred feet high with a plenty of talus of irregular blocks. The lava is more active; the surface is covered with boiling fountains, but they do not spout high. Because of the unquiet surface the crust cannot form as at the New Lake with regularity. There are occasional thin detached sheets which sink from time to time. The outer cone is composed of masses of lava that have been pushed up with much shattering and contortion. There are cones within cones, more like a crater. That it has been elevated is testified to by those who have occupied the Volcano House since 1875; and the greater part of the elevation has been effected the previous three years.

Captain Dutton ascribes the ebullition of the lava to steam and gases. Much of the visible steam comes from the fissures and numberless vent holes in the walls. Over the entire surface of the burning lakes is spread a pall of translucent vapor. Of the vapors he recognized the sulphur gases and considered that the bleaching of the brilliant orange and saffron colors of certain patches was due to hydrochloric acid.

To the southwest there existed another lake, which had been opened up about three years earlier, known as the "Old South Lake." Great quantities of pungent gas exclude from numberless fissures, and the surface is hot. There are occasional small eruptions over its surface.

THE AUTHOR'S VISIT IN 1883.

By the record of the visitor's book Captain Dutton was at the Volcano July 14, August 4, and September 12. The author ar-

rived there February 9 in the following year, in company with Rev. A. O. Forbes of Honolulu, who from his familiarity with the Hawaiian language was able to locate the proper positions of Kilauea iki, Poli o Keawe and Keanakakoi. Several days were spent in the vicinity. At the first inspection it was possible, after dark, to count ninety places from the Volcano House brink where fire was visible. This, of course, included many repetitions of single streams of which portions were concealed by intervening ledges. In general the phenomena observed were the same with those described by Captain Dutton and it will be unnecessary to repeat what has just been described. In the New Lake the lava seemed to spurt up in jets six to eight feet high, and they resemble the drawings of fire tempests on the surface of the sun as given in astronomical text books. The drops spun out to make Pele's hair were observed to dart a distance of eighteen or twenty feet. The description of the behavior of the lava in New Lake cannot be improved. I counted a hundred jets visible at one time. The cliffs about the lake were nearly fifty feet in height. The instant when the heat was most intolerable was just before the break-ups; and I accepted the explanation of Nordhoff, that this heat filled the crevices behind us because the stiffened crust prevented its escape into the air and it therefore made its way outward in the crevices. These periods of breaking up came regularly every hour. The outlet was at the north end; and February 9th it discharged copiously, so much so that it was impossible to return to the Volcano House by the direct road which had been taken in order to reach the lake. We had no difficulty in obtaining discharges of liquid lava by punching the dome-like structures held in position simply by a thin stiffened crust. The color of the flame contained more of the orange element than is apparent in ordinary fire. Halemaumau was reached with some difficulty and displayed the same freezing and breaking up observed in the New Lake. It was surrounded by three rough walls, rudely concentric with the borders of the fire. See Plate 35. It was a true crater in distinction from the application of the term caldera to the entire pit. The steam cloud rising from Halemaumau was turned either way according to the wind, and presented a general resemblance to the "Pine-tree" of Vesuvius.

In examining the fissures near to and far away from Kilauea, it was observed that they were generally parallel to the walls of the caldera. Apropos of the question of the relations of Kilauea to Mauna Loa, it was noticed that the ground falls off about five hundred feet before reaching the base of the latter dome. Hence

Halemaumau in 1883.

it seemed to be an entirely independent elevation; and the continuation of the basaltic sheets from every side till they met in the air over the pit would have made an eminence several hundred feet higher than the plain is at present.

March 30. Occasional overflows of lakes and crater gradually filling up. H. M. Whitney.

May 8. Visitors could not return by the same path on which they crossed the crater because of the lava overflow.

July 23. Fifteen boiling places in south lake. Lava poured into a cave on the side of the lake.

Aug. 9. Found only slight activity; but there was a fine display upon the following day. G. H. Barton.

Aug. 10. T. H. Davies. Both lakes: a new caldron; a break into a new cavern. Three rocky islands in south lake which changed their positions at night.

Aug. 13. One hundred and twenty-five feet of the bank fell into the New Lake.

Jan. 2. Submarine eruption off Cape Kumukahu. Mrs. S. J. Lyman.

Jan. 28, 1884. Both lakes in fusion. Rockets rise one hundred feet. Whole of New Lake boiling and surging like the sea. Pele's hair floating in the atmosphere.

Feb. 16. Old crater a sea of fire. New Lake burst into sudden activity.

March 3. The Little Beggar came into being between New Lake and Halemaumau. It was a dome two feet high from which a stream of lava flowed for several hundred feet. So called because it screamed viciously. C. H. Dickey.

March 17. Unwonted activity at New Lake.

May 15. New Lake twice as large as on April, 1882, the bank having caved in. South Lake or Halemaumau similarly enlarged. Little Beggar wholly new, as well as a breakdown between it and Halemaumau. W. R. Castle.

May 17. New Lake broken up the first time for several months. Went to floor of Halemaumau through a gap upon the north side. The path descends from ten to fifteen feet below the level of the lake. The lake rose one foot in less than twenty-four hours. The flow from the Little Beggar has nearly reached the north wall of the crater.

Nov. 5 to 11. Halemaumau active. Little Beggar noisy and blowing and sending forth a fresh stream. New Lake almost quiet.

Jan. 15, 1885. Crater near Halemaumau considerably built up since last visit. C. H. Wetmore.

July 29. New Lake less active, but Halemaumau and the Little Beggar exceedingly lively. E. C. Oggel.

Aug. 23. D. H. Hitchcock. Halemaumau now overtops the west bank. New Lake active; and streams from both of them flow over the crater floor.

Dec. 29. Quite a flow ran out of Halemaumau. E. P. Baker.

June 25 to Dec. 15. Both lakes very active. New Lake commencing to build a wall reaching one hundred to one hundred and fifty feet by March, 1886.

ERUPTION OF 1886.

The Halemaumau pit was completely filled up on the evening of March 6th, 1886. The lava that for nine years, or since the last previous important discharge (1877) had been accumulating and pouring over the floor from Halemaumau and New Lake, the latter five years old, attained the altitude of about 3,710 to 3,730 feet above the sea. The bottom of the pit of Kilauea was convex—the top being about one hundred and sixty feet higher than at the northern edge, while the general level averaged from two hundred and fifty to three hundred feet above the black ledge of 1840. Much of the old sulphur bank had been covered and the precipice at the southwest corner had mostly disappeared. Late in the evening there commenced a series of earthquakes so severe as to alarm J. H. Maby, of the Volcano House, and his family. Forty-three shocks were noted up to 8 A. M. of the 7th instant. After the fourth quake the light disappeared.

For three days the heated vapors had been uncommonly hot, but on the 6th and 7th instant ceased entirely. About midnight the lava disappeared. Plate 38 1 may show the convex outline before the eruption and Plate 38 2 the appearance of the contour afterwards. At first, however, the walls must have been more nearly vertical. Later large blocks of the black lava fell down, and there was a talus on all the steep slopes. From five hundred and seventy to five hundred and eighty feet thickness of rock fell away directly beneath the Halemaumau lake. The adjacent New Lake was comparatively shallow, one hundred and fifty feet. The central pit was about three hundred feet in diameter. Plate 36 shows the appearance of Halemaumau after the withdrawal of the lava; and Plate 37A a ground plan of the triangular area affected.

Compared with the earlier discharges this was very small. The main depression is of triangular shape with sides about 3,350 feet long, forming an area less than half a mile square. In extent

Halemaumau after the break down of 1886.

it is not very unlike Kilauea iki, though the basin carries less cubical content. On the east side there is a rudely semicircular depression where New Lake was, with its floating islands of rock. It makes a sort of shelf averaging one hundred and sixty-five feet in depth. The entire floor of the caldera is now the black ledge and the lower pit only the diminutive half a mile square area of Halemaumau; and the mass that has disappeared is so small that it is hardly worth while to seek to discover where it has gone.

It is to be expected that the liquid might ooze from one of the great fissures extending southwesterly for several miles towards Pahala, and be scarcely noticed as the region is mostly a barren uninhabitable waste. In my sketch[44] of this eruption, June 7 to 14, I have stated that besides the formation of the pit there were produced several large fissures in the neighborhood; one on the Poli o Keawe, at the sulphur banks near the Volcano House, and two on the road to Keauhou, two miles distant.

Mr. J. S. Emerson was at Kilauea between March 24th and April 14th, taking measurements for a map. He saw no molten lava, but could discern evidences of heat. Rev. Mr. E. P. Baker and Mr. Emerson both descended into the pit. On the eighth of June I descended to its very lowest depth, nine hundred feet below the Volcano House. To the depth of about three hundred and twenty-five feet, embracing nearly all the triangular area, the sides were covered by irregular slabs of pahoehoe, six or seven feet long, four or five feet wide and a foot thick. These were the crust of the lava at its greatest development, and they naturally fell on the slope so as to lie quite uniformly, though some fragments were tilted in every direction. The small lower pit, some six hundred feet across, was covered by the ordinary grayish lava blocks, and there were small jets of vapor. On the east side of this pit on June 8th, I found a hole about four feet in diameter, nearly vertical, reaching down perhaps as deep as the pit, to a mass of molten lava. Great volumes of steam and sulphur vapor poured out of this orifice, whose walls were lined with sublimed sulphur and Pele's hair. As this opening was situated in the midst of loose blocks of rock and widened out downwards, it was dangerous to stand near it; but the swashing of the liquid was distinctly audible and stones thrown down were heard to splash into the liquid. By my advice my companion withdrew from the edge of this opening, and immediately afterwards the rim fell down into the fire. Had not my friend taken my advice he would

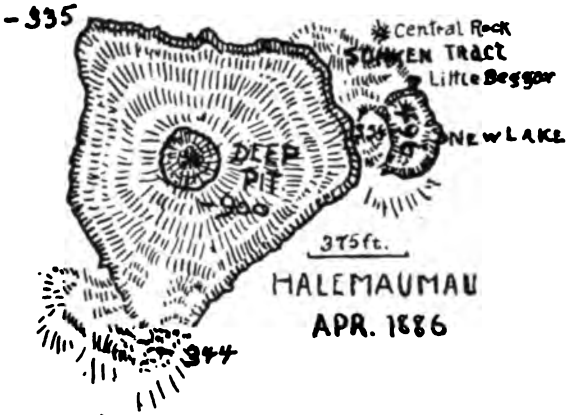
[44] Science, Vol. IX, p. 181. 1887.

have lost his life. About two hundred feet northwards from this opening there was a copious discharge of corrosive vapors, which increased in strength in the course of the following week. The fire in this opening continued to enlarge by absorbing the walls. June 25th two vents opened upon the west side of the pit, and lava flowed from the well originating June 8th, filling up the pit.

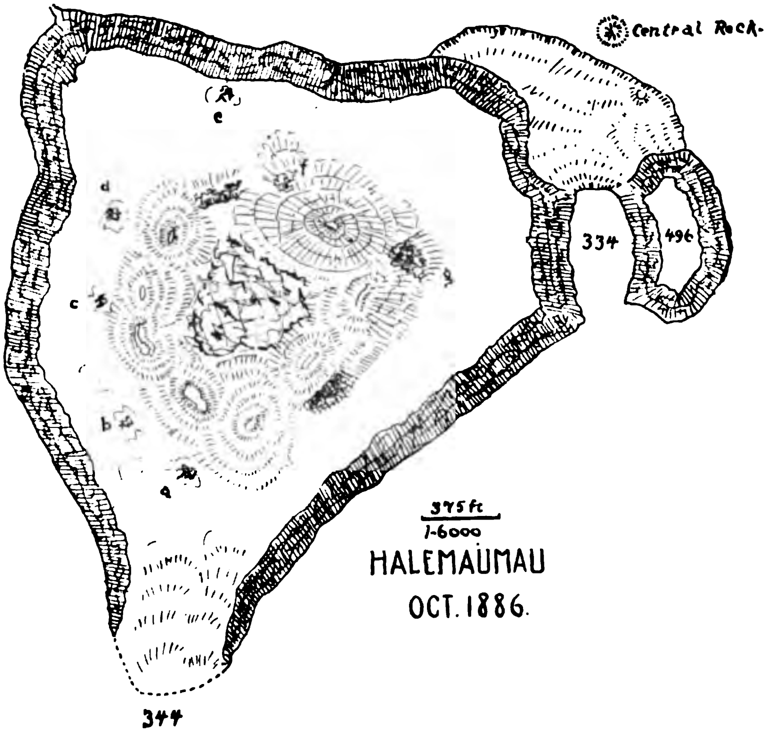
The further history of this spot is given by the statements of Professor L. L. Van Slyke who saw what was transpiring July 19th. The conical pit was not nearly filled up but there was a mound of lava blocks one hundred and fifty feet high taking its place, with a depression encircling it. A lava lake of about five acres in extent appeared in this depression and there were other active fires. He says: "Ascending the cone part way, I came to the edge of a deep hole or well, of rather irregular outline, four-sided, perhaps thirty or forty feet wide, and from sixty to seventy-five feet long, and not less than a hundred feet deep. The mouth was surrounded by masses of loose rocks, rendering approach to the edge impossible or very dangerous, except at one point; from this point I could see the bottom of the well, and that it was covered with hardened fresh pahoehoe. At one side the liquid lava could be seen as it was puffed out of a small hole every few seconds and thrown up a few feet. The puffing noise accompanying the ejection of the lava was quite like that of a railway locomotive, though louder. The aperture through which the lava was thrown out might have been three feet long and two feet wide. Immediately beneath the point where I was standing there seemed to be a constant and tremendous commotion, attended by a peculiar swashing noise, but I could not lean sufficiently far over with safety to see anything. Fumes of sulphur dioxide were coming up in abundance, but being on the windward side I was not greatly annoyed by them."

From the southeastern side he ascended the cone and came to "a second well or deep hole, where molten lava was visible. This well was nearly round, with a diameter of perhaps twenty or thirty feet, and a depth of about a hundred. * * * Like the other well, the sides were perpendicular. At the bottom was a cone having an opening at the top perhaps ten feet across; and inside liquid lava was boiling with intense violence, every few seconds throwing up a jet of lava, the spray of which came to the mouth of the well almost into my face."

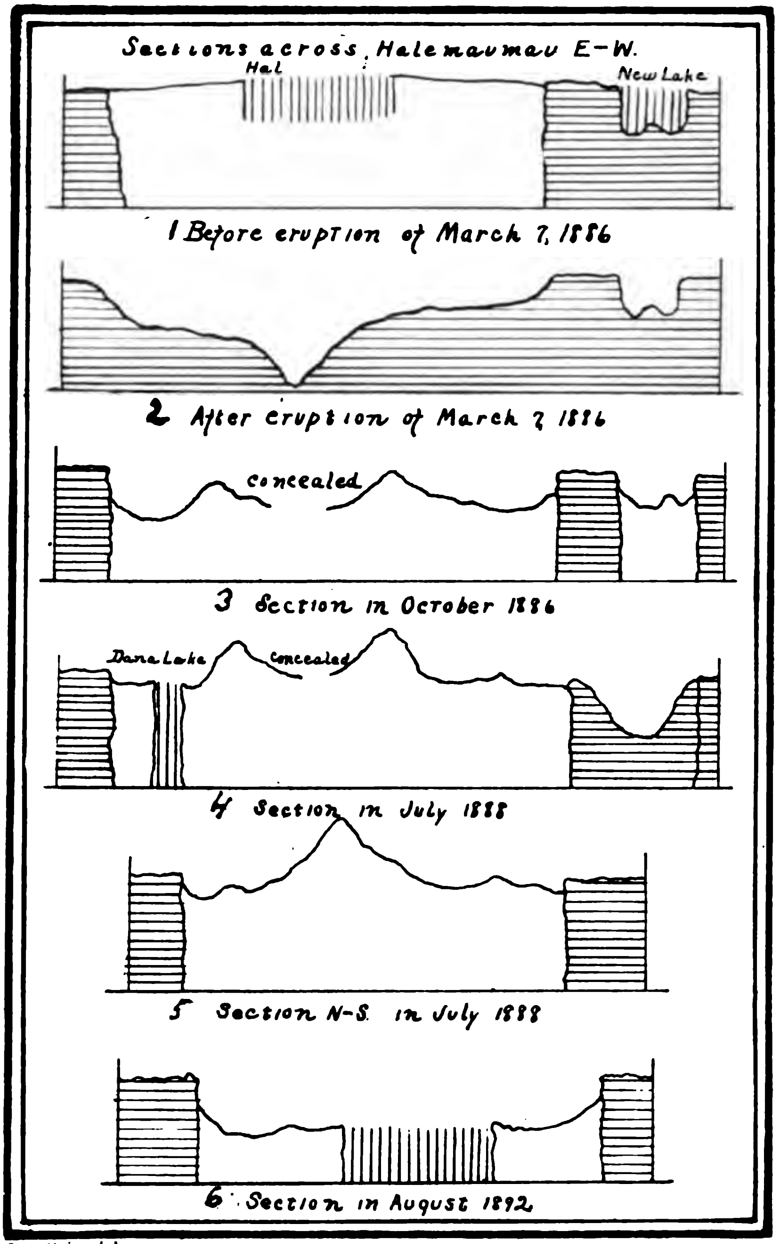
In addition to these holes, Professor Van Slyke visited a lake of lava located beneath the west wall of Halemaumau in the depression, and extending about four hundred feet to the "smoke



A. Ground Plan of Plate 36.



B. Ground Plan of Halemaumau, October, 1886.



SH. Wilkins. del.

Sections across Halemaumau, 1886-92.

jet." At first the surface was hardened and black; later there were spasmodic discharges of lava.

In September Mr. F. S. Dodge spent a fortnight at Kilauea observing the growth of the cone in Halemaumau and perfecting the data for a map supplementary to that of J. S. Emerson. A drawing made October 18th, Plate 37B, shows several steam holes upon the surface of the cone, a to g. Mr. Dodge noted the rise of the general floor due to the flow of the lava from Halemaumau. He also measured the debris-cone whose beginning had been described by Van Slyke. It was 1,080 feet broad from N. E. to S. W., 1,100 from E. to W. and nine hundred and thirty from N. W. to S. E. Hence as the width of the general basin was 2,300 feet there was a depression encircling the cone with a width of from five hundred to seven hundred feet. The highest point on the cone was not quite as high as the surrounding black ledge. A section showing the relations of the cone and the black ledge appears in Plate 38, No. 3.

The most important discovery made by Mr. Dodge was the fact that the whole basin with the cone was rising at the rate of nearly one foot daily. By January 14th, 1887, it had risen two hundred feet since October, 1886, as though floating upon the surface of a liquid lake. One of our illustrations shows this cone as it appeared in October.

Nov. 4, 1886. W. R. Castle noticed that heat was perceptible in the fissure of 1868 near Kilauea iki. He also visited Kamakaopule, a crater southeast from Kilauea iki. It is a pit five hundred feet deep, one-half of which is filled with sand. Steam was issuing from a crevice in the road quite near it. And it is said there is a very hot mound, now perceptible, (1908), west of the road, towards Kau.

In August, 1887, Kilauea was visited by Professor J. D. Dana, who has fully described the history of Halemaumau since the eruption in March, 1886.[45] He found the top of the cone to be high above the rim of the Halemaumau basin; and that it was literally a debris-cone made of fragments of the lava crust and not of loose scoria such as comes from the central vent. "In the basin about the cone, the chief boiling lava lake was on the west side, in full view from the top of the west wall. The lake was about one hundred and fifty by one hundred and seventy-five feet in its diameters. Although mostly crusted over, it showed the red fires in a few long crossing lines (fissures), and in three to five open places, half-way under the overhanging rock of the margin where the lavas are dashing up in spray and splashing noisily, with seem-

[45] **Characteristics of Volcanoes, 1890.**

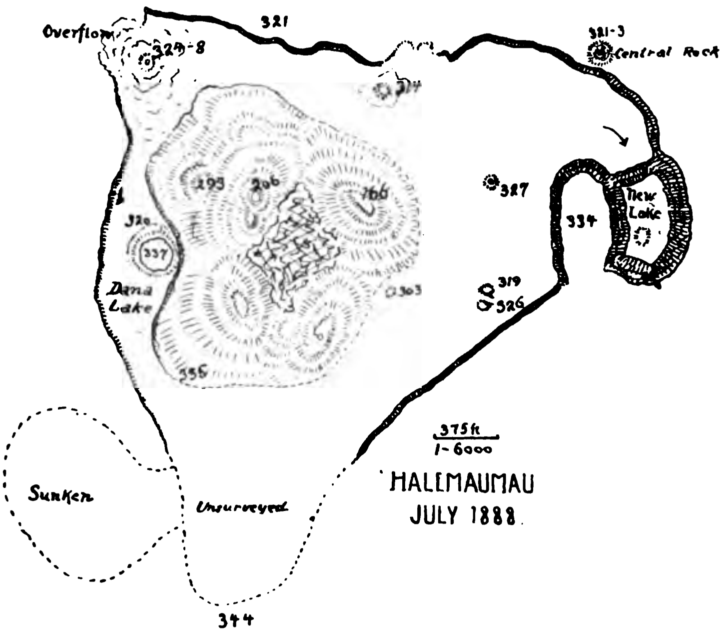
ingly the liquidity of water. Now and then the fire places widened out toward the interior of the lake, breaking up the crust and consuming it by fusion; yet at no time was there a projection of the lavas in vertical jets in a par-boiling way; nor was it too hot to stand on the border of the lake if only the face were protected. Although relatively so quiet, the mobility of the brilliant splashing lavas made it an intensely interesting sight. Occasionally the red fissures widened by a fusing of the sides as the crust near by heaved, and the lavas flowed over the surface. It was evident from the cooled streams outside, that now and then more forcible movements take place, followed by outflows over the margin; when the whole lake is in action. There were no true well-defined jets rising and falling over any part of the surface, like those of 1840, a condition requiring a little more heat; but the splashing at the margin, also due to the escape of vapor bubbles, had all the freedom of movement of splashing waves on a seacoast. The existence of the half-covered caverns along the margin, which the descriptions show to have been the most common feature for a score of years, was owing to the protection from cooling given by the overlying rock. All parts of the basin had been overflowed from fissures or temporary lava pools." This pool has since been named Dana Lake.

Our friend took great interest in the formation of the wrinkles on the surface of the cooled lava streams which give the look of tapestry folds, and are similar to the ropy lava of many authors. The stream of lava moves beneath the thin crust while it is cooling; and the little waves thus produced are too stiff to fall back to their original horizontality. The wrinkles must be at right angles to the direction of the movement. Good photographs of recently cooled lava show both these concentric tapestry lines and also many oven-shaped domes sometimes fifteen or twenty feet high. Commonly their surfaces are broken because of the running away of the molten lava inside and the inability of the roof to sustain weight. One often develops this fracture in walking over an old lava stream.

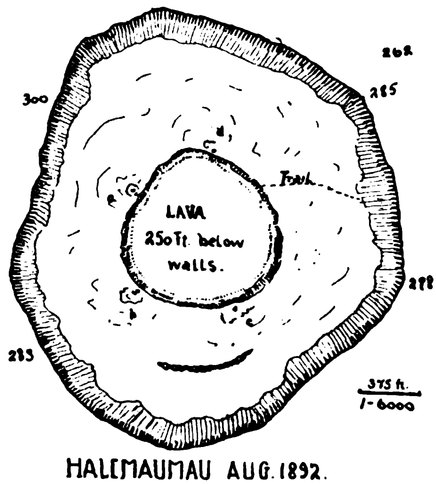
The vapors of sulphur may assist in the making of these ovens or domes, and will leave in the spaces below yellow and white incrustations and stalactites of glauber salt and gypsum. Instead of a scoriaceous crust when the lava exudes through fissures, the surface may be composed of glass, as the scoria material is not present.

The changes ensuing, seen in September, consist in a longitudinal division of the west wall, showing vapors rising from the whole length of the western section. By March 8th, 1888, the

PLATE 39.



A. Ground Plan of Halemaumau, July, 1888.



B. Ground Plan of Halemaumau, August, 1892.

A. Dana Lake.

B. View of Halemaumau in 1892.

cone had risen so high that the summit was "on a line with the outside walls of the crater beyond it, looking from the Volcano House." The whole mass, both the cone and the depression around it, had thus risen nearly forty feet since August.

Still further changes were apparent in July, 1888, illustrated in our reproduction of Mr. Dodge's map and section, Plates 38, 39A.

The conical mass seems to be subdivided into four elliptical cones encircling a space concealed by vapors of unknown depth, where molten lava may be existent. These subordinate cones are from one hundred and sixty to one hundred and twenty-five feet above the surrounding black ledge. The whole area of what was the depression of March, 1886, is also elevated above the black ledge, and lava from the central vents pours down into the old hollow where the New Lake once existed. On the west side of the cone the Dana lake has been further developed; there were six small discharging cones ten to twenty feet high outside of the central more highly elevated mass.

Dec. 22, 1888. L. A. Thurston says the activity is greater than ever before. From the Elephant's Head a flow of aa proceeded four days ago. A dozen blowholes. Lava lake has a confining wall built by itself, five feet thick. Lava rose and fell several times to the extent of three or four feet. A layer of Pele's hair four inches thick.

Feb. 21, 1889. Light over Kilauea. May and June remarkable activity. No eruption. Mrs. S. J. Lyman.

In May E. P. Baker wrote to Professor Dana that there was at this time a subsidence of eighty feet in the floor of Halemaumau which carried down the large central debris cone, leaving vertical walls about the great depression. There was a fissure in the floor of Kilauea which may have drawn off this lava and transported it a comparatively short distance. On July 4 there was a stream of lava from Dana Lake, flowing towards the cone.

July 18. A. B. Lyons says there is a cone of debris two hundred feet high, from whose base perpetual clouds of steam and sulphur are issuing. The mass floats upon lava deep down. It is in the center of a triangular depression 2,400 feet in diameter, surrounded by precipitous walls twenty to thirty feet high. On one side is a lake of lava one hundred and seventy-five by one hundred and twenty feet.

Jan. 2, 1890. E. P. Baker says a crack N. W. and S. E., corresponding to the outside of the area that has been lifted vertically, formed Nov. 4, 1889. Plate 40A represents the lake in 1890, the exact date not being given. Taken by Williams of Ho-

nolulu. Shows well the appearance of a black ledge encircling it and fragments of the congealed crust.

Jan. 2, 1891. L. A. Thurston reports great activity, Dana and the new lake boiling, throwing lava from forty to sixty feet. The wall about Dana Lake more conspicuous and the surface of the lava about ten feet above the surrounding country. Climbed the north wall of the central cone of Halemaumau.

SUBSIDENCE OF THE DEBRIS CONE.

It is worthy of note that in the next series of changes the area of the more elevated part of this cone becomes the depressed area of August, 1892, as shown by the section and map of that date; and a description of the changes follows.

S. E. Bishop. In the collapse of March 7, 1891, the debris cone, Dana and Maby lakes disappeared, leaving a pit seven hundred feet deep. Lava soon returned, and for one year has been gradually rising. In Dana Lake the lava had issued quietly from the center towards the walls and descended carrying sections of the crust. Now the edges are quiet. The current starts from east of the center and flows westward. Pieces disappear in the vivid melee of the center. The cone form of Halemaumau becomes more distinct. (Written April 11, 1892.)

There was a slight earthquake when the change took place, and it was exactly five years between the last two collapses. As the debris cone was about two hundred feet high its apex was only eighty-eight feet below the Volcano House—the highest point attained by the rock during the whole history of the volcano, or 3,955 feet above the sea. The melted lava probably reached the height of three hundred and seventy feet below the Volcano House.

March 18, 1891. A sheer precipice around Halemaumau. Depth a little less than in 1886. E. P. Baker.

May 19. W. R. Castle says that Halemaumau is a profound abyss 1,800 feet in diameter and nearly three hundred feet deep. Mr. E. N. Hitchcock succeeded in making the perilous descent to the bottom over large blocks of lava. On the northeast side of the lake is a cone ejecting lava.

Sept. 14. E. P. Baker. In May the lava lake was four hundred to five hundred feet below the edge. Now it is about two hundred. Lava flows from N. W. to S. E.

Nov. 30. H. M. Whitney says the lake is 1,000 to 2,000 feet across, throwing up several large jets and thousands of small

ones. There are two openings near the center allowing the lava to ascend and descend.

Feb. 12, 1892. L. A. Thurston. Diameter of the pit 2,500 feet. It is two hundred and fifty feet down to the black ledge, which is twenty-five feet high and two hundred feet broad. It is 1,300 feet from bank to bank of the lake next to the black ledge. J. M. Lee says that two months ago the molten lava sank one hundred and fifty feet below the level of the black ledge. After one month it began to rise again and lacks now only twenty-five feet of its pristine level. Lava boiling with bursts of spray twenty-five feet to fifty feet. No upward thrust. The filling is by overflow from the central lake.

The condition of things in Kilauea after the changes of March 7th, 1891, have been very intelligently described by Professor A. B. Lyons.[46] He spoke first of the appearance in 1889, and found in 1892, July 11, everything so changed that nothing in the vicinity of Halemaumau was recognizable. The debris-cone with the attendant clouds of steam and smoke had vanished. From the hotel, one would say that the volcano has entirely disappeared; and nothing suggestive of great importance was perceptible till the pit itself was close at hand, which was enclosed by a precipice constituting a circular rampart two hundred and fifty feet deep, half a mile in diameter. The sides consisted of irregularly bedded lava varying in hue from gray to brick red; the floor of fresh black pahoehoe with a fluid center or lake partly quiet and partly boiling like a witch's caldron. The lava pool occupies about fifteen acres with banks from five to ten feet high.

The lava blocks are loosely piled beneath the precipice over which by care it is possible to make one's way. The lake is twenty-five to thirty feet higher than the base of the walls of the pit. On the south side the lake is held in place by a sort of levee of slight thickness over which the lava pours in a magnificent cataract not less than fifteen feet in perpendicular height.

So much lava rises from below that the level of the lake is constantly rising and changing its area. One evening there were overflows from three different points at once, and within two hours' time fifteen acres of the black lava were inundated. The heat is intense, and one is in danger of being bombarded by the spurts of the fiery liquid. It was dangerous to go to leeward of the lake because of the unexpected flows of lava

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[46] Thrum's Annual for 1893.

which might cut off one's retreat or raise the temperature of an inclosed space to an unendurable degree.

A more minute description has been given by Professor Lyons as he sat by the brink of the lake in a secure position. "As daylight fades the walls of the pit begin to glow with the reflection of the lurid volcanic fire; the clouds which the trade wind brings over the crater catch the same unearthly light which brightens with the outburst of each new fountain below. As the darkness deepens, the light from the lava jets and surges becomes fairly dazzling to the eyes, and the action is kept up almost without intermission, now at one point only, again along half the circumference of the lake, or over areas of an acre or two in the center. There were certain lines along which the ebullition would take place repeatedly, sometimes continuing hours together, sometimes only momentarily at somewhat regular intervals; the lava would be thrown to a height of fifteen to thirty feet, small clots, appearing like sparks, shooting often to double that height. The peculiar sullen or angry roar of the fiery surf could be often distinctly heard and was at times startlingly loud. Frequently, too, the radiated heat could be distinctly felt when there was an unusual outburst.

"The crust which by daylight had appeared to be uniformly black is seen in the night to be crossed with a net work of cracks and fissures through which the light of the glowing metal can be seen. These appear sometimes simply as sharply defined lines, forming a more or less intricate pattern, which is, however, momentarily changing. This is when the lava crust is under no particular tension. Again the lines of light will be seen perhaps sharply defined on one side but shaded through tints of red to darkness on the other, the effect being produced by a force drawing the crust bodily away from the crack on one side. Frequently a crack will be shaded in this way on both sides, and will presently divide into two parallel lines of light which will slowly separate from one another. When the current pushes the crust before it on the other hand, it will yield suddenly, one edge will be forced up and the other down, so that presently the crust will break into blocks which will be successively engulphed. Then a fountain will perhaps suddenly burst through the crust, tossing about its fragments, some of them a ton's weight, like bits of drift wood in the eddies of a mountain torrent. Then at some point the flood will rise above its embankment, and almost without warning a lava stream will begin to flow, becoming presently a river of living fire. The whole pit will be ablaze with vivid light; the

flood will spread until it reaches the foot of the enclosing wall, glowing at first like molten iron drawn from the smelting furnace, then changing to a lurid red except where the feeding river continues to flow, and so fading until it shows only here and there glaring eyes of fire looking out from cavernous depths. It is as futile to attempt description as for the painter to try to present on canvass anything but a travesty of a volcano."

The conditions as above described are shown in the drawing of Mr. Dodge for August, 1892, Pate 39B.

Explanation of Plate 39B. a. b. c. small fire openings in the floor, which average two hundred and sixty-five feet below two hundred and eighty-three. Diameter of lake N. E. and S. W. eight hundred and twenty-five, E. and W. eight hundred and forty, S. E. and N. W. eight hundred and ten. Diameter of Halemaumau N. and S. 2,500, E. and W. 2,250, N. E. and S. W. 2,340, N. W. and S. E. 2,400. The ledge south of the lake seems to be the precursor of a ridge developed later.

Sept. 28, 1892. E. P. Baker. Went to molten lava ascending the rim. No large flows from it. Lake higher than before; about two hundred and forty feet down.

Jan. 9, 1893. Lake eight hundred and forty feet long, eight hundred and twenty-five feet wide; the rim two hundred and forty feet below top of cliffs, which are about sixty-five feet high and rise twenty-five feet above the hot circumambient black ledge. Is rising from accretion not elevation.

Jan. 26. Rim broken in a dozen places, and lake lowered twenty-five feet.

Feb. 1. Height of cliffs said to be one hundred feet.

May 14. Charles Nordhoff. In January, 1873, one had to ascend a hill to reach the lake; now there is an ugly descent of perhaps fifty feet and then a slight climb to reach the lava. Action less mild than before.

June 20. E. P. Baker. Lake one hundred feet below banks, or one hundred and forty feet lower than at previous visit.

July 29. W. R. Castle speaks of the lake one hundred to one hundred and seventy-five feet down, which has built a rim about itself thirty-five feet high. The rim gives way and the lava falls a foot; then rises from accretion and then falls again. Every outburst of lava accompanied by fumes of sulphur.

Aug. 4. Lake full to the brim.

Dec. 25. W. Goodale. Since 1847 the uprising of the whole floor has been the noticeable feature of the volcano, and after every breakdown the lava comes back to Halemaumau. This word means "the fixed, lasting, unchanging, everlasting, ever

continuous, house." No sense in saying "Fern house" or "House thatched with ferns;" any such structure was back of the Volcano House. (Westervelt.) No Hawaiian has ever written the name Halema'uma'u; and they call the Caldera Ka lua o Pele "The pit of Pele."

Jan. 8, 1894. Entire lake very active; tending to fill the pit.

March 20. F. S. Dodge. Whole pit filled up. Lake eight hundred by 1,200 feet, two hundred and eighty-two feet below Volcano House. Has risen two hundred and forty feet in nineteen months.

March 21. The north wall suddenly elevated eighty feet above the lake. J. M. Lee.

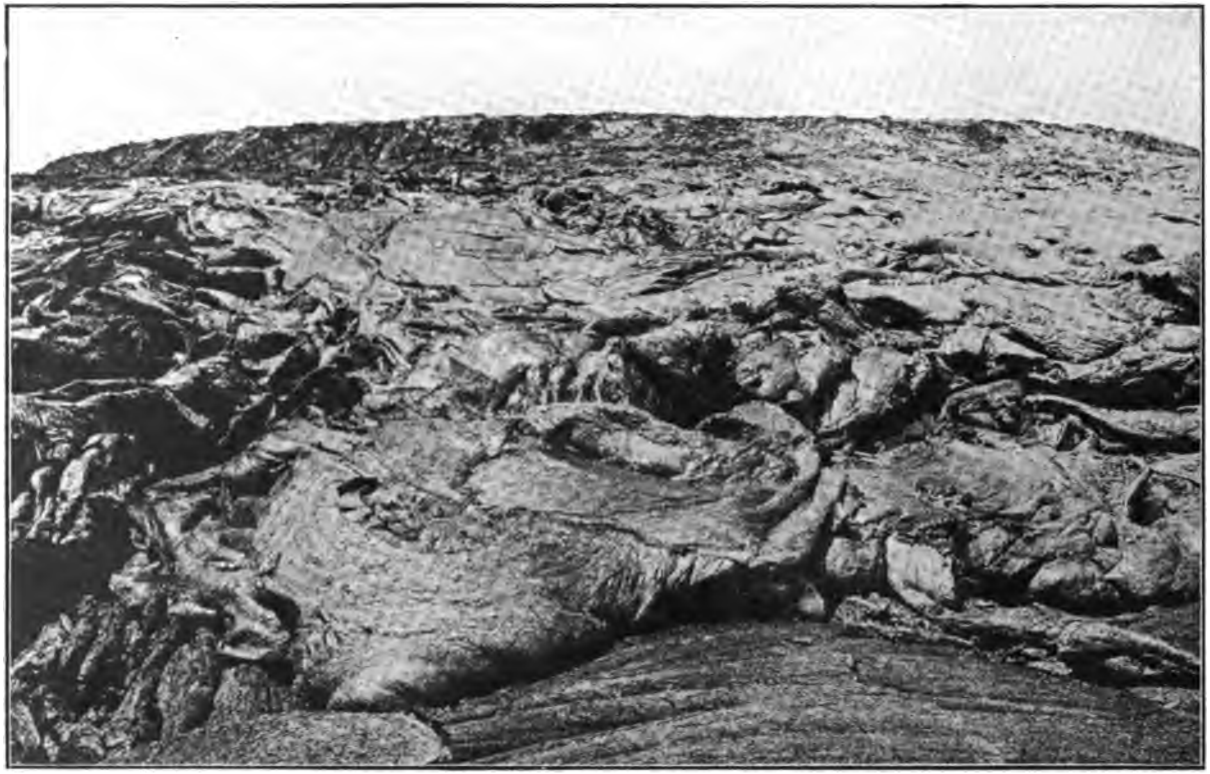
March 26. W. R. Castle. Entire lake in condition of intense agitation, spouting and boiling with lava flowing over the sides. Suddenly on the west side stones, lava and dust thrown high into the air with spouting columns of fire, and in less than five minutes the north bank was tilted up to a height of one hundred feet, leaving an abrupt wall over the lake with a steep, broken slope toward the north. It appears to have been lifted up by lava pressing from no great distance below, and a stream has constantly emerged from the northeast slope of the hill ever since. Much more steam than usual comes from all the cracks, even up to the sulphur banks.

THE BREAKDOWN IN 1894.

For about two years the liquid had been accumulating, till finally it filled the pit and oozed forth from the highest part of the immense column. The borders of the fused lava cooled more quickly than the interior; whence it resulted that the refrigerated mass accumulated around the edges of the pool and kept increasing till a basin was formed, very much like the bowls in the Yellowstone Park that accumulate from the cooling of the lime compounds in the water except that the refrigerated mass was outside of the basin; and the shape produced might be likened to an inverted saucer. The Frontispiece shows this lake when at its best development, and Plate 42 is a view of the edge of the same at the south end taken from below.

This eruption marks a climax in the history of the volcano, representing the highest elevation attained by any lava lake in Halemaumau, two hundred and eighty-five feet below the Volcano House, or 3,755 feet above the sea. Pele may excel this record in the future; and in that case she will probably send a burning stream into Kau, for the barrier to be overcome there is only about fifteen feet.

PLATE 42.



South Rim of Halemaumau from the south.

In the early part of July Mr. L. A. Thurston and party witnessed this unprecedented series of changes. The account of it was spread upon the Volcano House record and sent to the *P. C. Advertiser* from which the following notes are compiled:

"Upon arriving at the volcano on July 5, 1894, the principal change since Mr. Dodge's visit was found to be the sudden rising of the north bank of the lake, covering an area of about eight hundred feet long by four hundred wide, which, on the 21st of March last was suddenly and without warning elevated to a height of eighty feet above the other banks and the surface of the lava, the lake being then full. The raised area was much shattered. Two blow-holes shortly afterward made their appearance on the outer line of the fracture. April 18th the hill thus formed began to sink, and on July 5th was only about thirty feet above the other walls of the lake. On the evening of July 6th, a party of tourists found the lake in a state of moderate activity, the surface of the lava being about twelve feet below the banks.

"On Saturday, the 7th, the surface of the lake raised so that the entire lake was visible from the Volcano House. That night it overflowed into the main crater, and a blow-hole was thrown up, some two hundred yards outside and to the north of the lake, from which a flow issued. There were two other hot cones in the immediate vicinity which had been thrown up about three weeks before. On Sunday, Monday and Tuesday following [8, 9, 10], the surface of the lake rose and fell several times, carying from full to the brim to fifteen feet below the edge of the banks.

"On the morning of the 11th the hill was found to have sunk down to the level of the other banks, and frequent columns of rising dust indicated that the banks were falling in. At 9:45 A. M., at which hour a party reached the lake, a red-hot crack from three to six feet wide was found surrounding the space recently occupied by the hill; the hill was nearly level; the lake had fallen some fifty feet, and the wall of the lake formed by the hill was falling in at intervals.

"The lava in the lake continued to fall steadily, at the rate of about twenty feet an hour from ten o'clock in the morning, until eight in the evening. At 11 A. M. the area formerly occupied by the hill, began to sink bodily, leaving a clean line of fracture; the line of this area was continuously leaning over and falling into the lake. From about noon until eight in the evening there was scarcely a moment when the crash of the falling banks was not going on. As the level of the lake sank, the greater height of the banks caused a constantly increasing

commotion in the lake as the banks struck the surface of the molten lava in their fall. A number of times a section of the bank from two hundred to five hundred feet long, one hundred and fifty to two hundred feet high, and twenty to thirty feet thick, would split off from the adjoining rocks, and with a tremendous roar, amid a blinding cloud of steam, smoke and dust, fall with an appalling down plunge into the boiling lake, causing great waves and breakers of fire to dash into the air, and a mighty 'ground swell' to sweep across the lake dashing against the opposite cliffs like storm waves upon a lee shore. Most of the falling rocks were immediately swallowed up by the lake, but when one of the great downfalls referred to occurred, it would not immediately sink, but would float off across the lake, a great floating island of rock. At about three o'clock an island of this character was formed, estimated to be one hundred and twenty-five feet long, twenty-five feet wide and rising ten to fifteen feet above the surface of the lake. Shortly after, another great fall took place, the rock plunging out of sight beneath the fiery waves. Within a few minutes, however, a portion of it, approximately thirty feet in diameter, rose up to an elevation of from five to ten feet above the surface of the lake, the molten lava streaming off its surface, quickly cooling and looking like a great rose colored robe, changing to black. These two islands, in the course of an hour, floated out to the center, and then to the opposite bank. At eight in the evening they had changed their appearance but slightly. By the next morning they had, however, disappeared.

"About noon the falling lava disclosed the fact that the small extension at the right of the lake was only eighty feet deep, and it was soon left high and dry; simply a great shelf in the bank, high up above the surface of the lake. As the lava fell, most of the surrounding banks were seen to be slightly overhanging, and as the lateral support of the molten lava was withdrawn, great slices of the over-hanging banks on all sides of the lake would suddenly split off and fall into the lake beneath.

"As these falls took place the exposed surface, sometimes a hundred feet across and upwards, would be left red-hot, the break evidently having taken place on the line of a heat-crack which had extended down into the lake.

"About six o'clock the fallen bank adjacent to the hill worked back into a territory which, below fifty feet from the surface, was all hot and in a semi-molten condition. From six to eight o'clock the entire surface of this bluff, some eight hundred feet in length and over two hundred feet in height, was a shifting

mass of color, varying from the intense light of molten lava to all the varying shades of rose and red to black, as the different portions were successively exposed by a fall of rock and then cooled by exposure to the air. During this period the crash of the falling banks was incessant. Sometimes a great mass would fall forward like a wall; at others it would simply collapse and slide down making red-hot fiery landslides, and again enormous boulders, as big as a house, singly and in groups, would leap from their fastenings and, all aglow, chase each other down and leap far out into the lake. The awful grandeur and terrible magnificence of the scene at this stage are indescribable. As night came on, and yet hotter recesses were uncovered, the molten lava which remained in the many caverns leading off through the banks to other portions of the crater, began to run back and fall down into the lake beneath, making fiery cascades down the sides of the bluff. There were five such lava streams at one time.

"The light from the surface of the lake, the red-hot walls, and the molten streams lighted up the entire area, bringing out every detail with the utmost distinctness, and lighted up a tall column of dust and smoke which rose straight up. During the entire period of the subsidence the lava fountains upon the surface of the lake continued in action, precisely as though nothing unusual was taking place.

"Although the action upon the face of the subsiding area was so terrific, that upon the portion between the falling face and the outer line of fracture was so gradual, that an active man could have stood on almost any portion of it without injury. Enormous cracks, twenty to thirty feet deep, and from five to ten feet wide, opened in all directions upon its surface, and the subsidence was more rapid in some spots than in others, but in almost all cases the progress of action was gradual, although the shattered and chaotic appearance of the rocks made it look as though nothing but a tremendous convulsion could have brought it about.

"Another noticeable incident was the almost entire absence of sulphurous vapors, no difficulty in breathing being experienced directly to leeward of the lake.

"At nine o'clock the next morning the lake was found to have sunk some twenty feet more: the banks at the right and left of the subsiding area, which had been the chief points of observation the day before, had disappeared into the lake for distances varying from twenty-five to one hundred feet back from the former edge, and the lower half of the debris slope had been swallowed up in the lake, disclosing the original

smooth black wall of the lake beneath at a considerable overhanging angle.

"At the level of the lake, and half filled by it, was a great cavern extending in a southeasterly direction from the lake. The dimensions were apparently seventy-five feet across and fifteen feet from the surface of the lake to the roof of the cave. It could be looked into from the opposite bank for about fifty feet. This may have been the duct through which the lava had been drained, although it manifestly was not at the bottom of the lake, for up to July 16th, that had continued to rise and fall from five to ten feet a day, and constantly threw up fountains, somewhat more actively than before its subsidence. The entire area of subsidence is estimated to be a little less than eight acres, about one-half of which fell into the lake.

"While the break-down was taking place there were many slight tremors of the banks, generally resulting in the precipitate retreat of the observers from the edge, but although the danger was great the spectacle was so grand and fascinating that the party returned again and again to watch it.

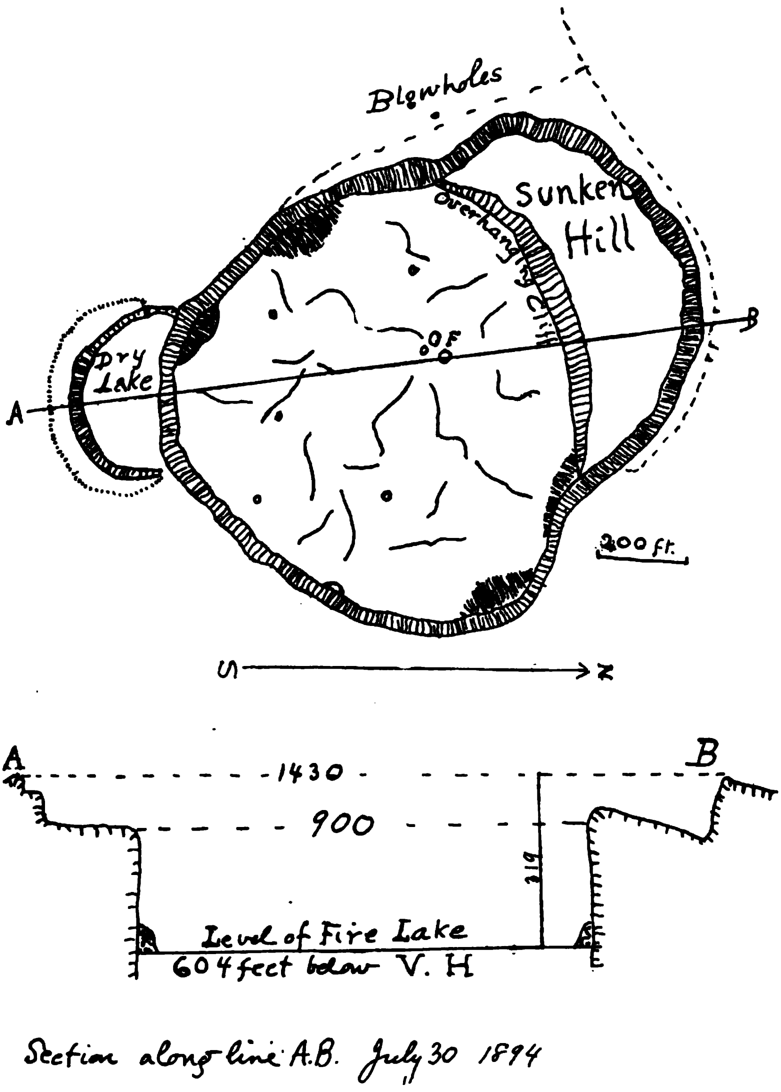
"At the Volcano House two slight earthquakes were felt on the afternoon of the 11th and one vigorous one at 2 A. M. on the 12th. During the week several slight shocks were felt in the town of Hilo, thirty miles away, yet none were felt at Olaa, half-way between, nor at Kapapala fifteen miles in the opposite direction, although the latter is a place peculiarly susceptible to earthquakes."

Plate 43 is a ground plan and section of the lake July 30, modified somewhat from the sketch made by F. S. Dodge in the record book. The thickness of the lava escaping proves to be three hundred and nineteen feet, and its level after the collapse six hundred and four feet. The acreage of Halemaumau is put at 23.67: of the lake 13.65.

Statement of W. F. Frear. July 24 to August 4. Lake active. "Old Faithful" playing once or twice a minute, coming up each time as one, two, or three large bubbles, and then being quiet till the next burst, the other fountains four to six generally at a time, playing often several minutes before quieting down. Old Faithful apparently held the same place in March, 1892, for four different days.

Three points of special interest. 1. Change in the height of the lake. This and the place of the walls believed to be essentially the same after the drop of July 11 and on July 24, but changed after July 27. 2. Falling of the walls July 28-29, when the lake fell about fifteen feet. Aug. 2 there was more

PLATE 43.



Ground Plan and Section of Halemaumau, July 30, 1894.

falling, and two days later the lake fell twenty feet more. 3. New islands appeared; one having the shape of an angle, flat, with its greatest length one hundred and thirty feet. Another of oval shape Aug. 4, twenty or thirty feet long, ten or twelve feet high.

This account is supplementary to the history of the collapse. During the time of the greatest activity the great heat of the lava made it necessary for visitors to view the proceedings from Uwekahuna.

THE BREAKDOWN OF 1894 AS DESCRIBED BY S. E. BISHOP.

In the issue of Nature for September 4, 1902, Dr. S. E. Bishop presents his views of the changes in Kilauea in 1892-4:

The recent destructive eruption in Martinique has revived interest in the question of the causes of volcanic action. Only lately have I become sensible of the peculiar value of some observations of my own as evidence of the *primary* force which impels the ascent of lava from its interior habitat, as distinguished from the explosive violence caused by steam generated by the encounter of the ascending lava with ocean and other surface waters.

I have long believed the primary force to reside in the expansion of the gases originally occluded in the magma, ever since its first condensation from the nebula. Whenever released from solidifying pressure by disturbances of the superincumbent crust, the intensely hot magma bursts into a viscid foam and pushes upwards. In a quiet volcano like our Kilauea, meeting no water to generate explosive steam, the lava wells up continuously and steadily in a comparatively gentle fountain, which displays effervescence only on the surface.

In support of this opinion I beg to offer positive evidence contained in certain facts observed by myself in Kilauea during April 8-14, 1892, and on August 28, 1894. The volcano had been in very steady and uniform action for nearly two years before the earlier date, and so continued until a short time after the latter date, or nearly five years in all of a quiet, continuous and rather copious welling up of lava, wholly unattended by any explosive action.

On the earlier date I carefully observed the then existing lava-lake during six successive days. This lake occupied the center of the inner crater, called Hale-a-mau-mau, or Fern-hut. The main crater called Kilauea is nine miles in circumference, averaging four hundred feet in depth, and rather unevenly floored with recent lava. Southwest of the center is the

inner pit of Hale-a-mau-mau. This pit was at that time nearly circular and 2,400 feet in diameter, with vertical sides averaging one hundred and fifty feet down to the talus. Before the welling up of lava began in 1890, the pit had been about 700 feet deep. In two years the lava had risen four hundred feet, and stood within three hundred feet of the rim and main floor.

A lake of liquid lava, covered by a thin, spongy film, occupied the center of the pit. This lake was nearly circular, averaging 850 feet in diameter. It was bordered by a low dyke, which partially restrained its frequent overflows. Outside the dyke, freshly congealed lava sloped away to the talus. By day the crust-film was grey to the eye, but by night a deep red. It was traversed by numerous fissures of white fire. During the whole time three fountains of lava were welling up with somewhat regular intermittence, and three smaller ones at irregular intervals. There was no explosive action whatever.

The largest fountain was about one hundred and twenty feet southeast of the center of the lake. It played with great regularity about three times in a minute, rising in a round billow twenty-five feet high and fifty feet in diameter, bursting at the top and falling back to level, its discharge moving in a broad stream towards the center of the lake. The fling of spray from its summit rose to forty or fifty feet above the level.

West of this central fountain were two others of very different character, being more spasmodic in activity, but never long quiet. Occasionally they would unite their forces for half an hour at a time, forming a stationary line of one hundred and thirty feet of spraying billow much like a surf-comber with flying spray. This stationary surf-wave was fifteen feet high, incessantly flinging its spray ten feet higher along its whole length. In the night, the effect of these fountains was extremely brilliant and was attended by loud metallic crashing.

The other three fountains were smaller, near the borders of the lake, and often quiet for hours together.

During the thirty months' interval between my two visits, the gradual elevation of the fire-lake continued quite uniformly, as attested by occasional photographs. By its frequent overflows it had built itself up to a height of fully fifty feet above the previous main floor of Kilauea, so that it formed an extremely low truncated cone, surmounted by the level lake, to the edge of which visitors daily approached.

About March, 1894, a recession began, which ended in a final collapse of activity. The lake soon sank some hundreds of feet, carrying with it the sides of a circular pit, about 1,400

feet in diameter, and central to the original 2,400-foot pit. When I saw it in the following September, the fire-lake was not less than five hundred feet below the rim. During the evening, masses of rock frequently crashed in, driving heavy surges of fire far up the talus. There was a good deal of steam-cloud slowly rising, charged with sulphur. During my previous visit, all vapour had seemed to be absent, and I made the circuit of the pit without encountering sulphur. Subsequent photographs had also indicated the absence of vapor from the lake.

I now have to add an important observation. To my great surprise, at this last visit, I perceived that the three fountains above described were in full activity and in the same relative position as before, although during the thirty months the level of the lake had risen three hundred and fifty feet and had then fallen five hundred feet. By what system of supply-ducts such fountains had been so long maintained was a mystery concealed in the fire-depths. But the fact of a marvelous steadiness and uniformity of action was obvious. For a long period a uniform and gentle outpour of effervescence had been maintained. It has persisted for two years and a half, throughout all the immense changes.

I submit as the unavoidable conclusion that the source of supply for this five years' outpour of gently effervescing lava was in an interior magma which itself contained the impelling force in its own originally occluded gases. For its activity this source was wholly independent of any encounter with water to generate steam. Expanding steam evidently had no part in that steady, quiet, persistent activity in the fire-lake of Kilauea.

I would add that the exceptionally quiet and uniform activity of Kilauea seems to render it one of the most important of all volcanoes for study. I regret to say that since the collapse nearly eight years ago no lava has appeared in the crater, except a small quantity last June, which has again gone out of sight.

KILAUEA AFTER 1894.

For several years the volcano was quiet.

Sept. 16, 1894. There was a lake deep down, visible only at intervals because of vapors. W. J. Forbes and David Thrum.

Dec. 6. The fire in the crater quietly disappeared in the night. J. M. Lee.

Jan. 3, 1896. Lava flowed from a hole two hundred and fifty feet above the extreme bottom of the pit and accumulated in a pool two hundred and fifty by two hundred feet in size. Depth estimated at four hundred and fifty feet. Peter Lee.

Fire disappeared again Jan. 28.

May 18. Fire extinct, though vast clouds of steam pour out. H. M. Whitney.

July 11. Lake measured one hundred and fifty by one hundred feet. Lava from the hole as before. This lake disappeared after a duration of three weeks.

July 28-31. English geologist, W. D. B. says, Crater, 1,500 feet across; depth to fire, six hundred and fifty to six hundred and seventy feet; diameters three hundred and thirty to four hundred and thirty feet. Lava both rose and fell thirty feet. Small cone twenty feet high at northeast corner throwing out lava and vapors. Spectroscope showed faintly the lines of sodium and hydrogen, but not of iron or gases. Degree of heat far below that given by Dana.

Aug. 26. A. L. Colsten collects data for map. His plan of Halemaumau is shown in Plate 44A. His letters A. D. correspond to B. A. of an earlier plate. E is the place for viewing the fire pit. X Y Z, are the blow-holes. B and C are points of view on the south side. The fire lake is seven hundred and fifty-seven feet, like all the others, so much below the Volcano House as the datum point. A is two hundred and seventy-six, other points on the edge of the sunken pit two hundred and eighty-two, two hundred and seventy-five, two hundred and seventy-two; the blow-holes, X, Y, Z, two hundred and sixty-eight, two hundred and sixty-nine, two hundred and seventy-two; E, two hundred and seventy. D beyond Dry Lake two hundred and fifty-seven, two hundred and sixty. C, two hundred and seventy-five; within the sunken pit three hundred and forty-two, five hundred and fifty-nine; upon its inner edge, two hundred seventy-four, three hundred and six. Area of the pit 24.40 acres; of the lake, 3.41 acres. The spouting cone is thirty-two feet high, throwing up lava spray one hundred feet. The hachure lines show well the fact that Halemaumau is at the top of a shallow cone.

June 24, 1897. A little fire. Lasted for three days. J. M. Lee.

Jan. 14, 1898. Not a sign of life. Frank Godfrey.

Feb. 25, 1899. Excursion party report no activity.

March 26, 1899, the Hon. L. A. Thurston writes, the outer rim of the pit is the same as that figured in 1894, being by estimate eight hundred feet deep, one hundred and fifty feet

in diameter at the bottom. A pit formed March 24th, in which no bottom can be seen. There is a steep vertical wall on the north side for three hundred feet down. On the south side the vertical wall extends about six hundred feet down, before coming to the debris. At the opening of March 24th a loud noise was heard; a great cloud of dust arouse, produced probably by a slide.

Prior to the filling of the pit a dense cloud of smoke was pouring out of it. It ceased almost entirely after the slide. The heat-crack parallel with and four hundred feet distant from the north wall of Halemaumau has greatly increased in heat since December last when I last saw it. It is sizzling hot a foot back from the edge and shows a cherry red about twenty feet down. This is the first fire seen in the crater since June 24, 1897.

In June and July, 1899, I inspected the pit and its surroundings. Because of a constant dense cloud of steam and vapors the bottom could not be seen. In an opening a short distance to the north of the pit, it was possible to descend and observe the formation of small stalactites and incrustations of gypsum in a temperature suggestive of 140° F.; and an eighth of a mile farther northerly was a larger similar opening, though less hot. Paper could easily be ignited in cracks near by.

March 2, 1900. There was a breakdown filling the "bottomless pit" and some fire. L. A. Thurston.

September. W. M. O'Shaughnessy. Smoke predominates Observed altitudes as follows: Where the road from the Volcano House reaches the lava four hundred and sixty-five; halfway to Halemaumau, four hundred and fifteen; higher edge of Halemaumau two hundred and seventy; depth of the pit not attainable.

June 6, 1901. A visitor lighted a stick in a crack some twelve feet down.

June 27. D. S. Jordan and party saw glowing lava deep down in one of the cracks.

CONDITIONS IN 1902 AND LATER.

After a long season of quiet slight activity is resumed. Hon. L. A. Thurston writes in the Record Book of the Volcano House, February 14th, as follows:

The outlines of the pit of Halemaumau are essentially the same as when last reported (1900). Very little sulphur vapor arises from two or three spots on the north and east sides. There is a clearly defined recent flow of black lava at the extreme bottom of

the pit, the first in several years. The heat crack on the north side is hotter than ever before.

The same writes June 12:

The debris on the north side of the pit has dropped down. Dense sulphur vapor rises from the extreme bottom of the pit and fills it so completely that nothing can be seen for much of the time. Two hundred feet from the bottom of the east side there is a bright light, seemingly emanating from fresh lava in a cave. The lava seen February 14th has been covered by debris. Apparently the action in the pit is the beginning of its filling up. Steam still rises from the big cracks running from Keanakakoi towards Kau, although they are nearly filled with drift sand and pumice stone.

August 25, 10 P. M., Mr. Waldron says a lake four hundred feet in diameter has just formed in the bottom of Halemaumau on the Kau side. It has the shape of an irregular quadrilateral. There was no earthquake here, but there were shocks at Hilo at 11:45 P. M., August 24th; at 3 P. M. the 25th and 3:15 A. M. the 26th.

September 12, Hon. L. A. Thurston says: The new lake has subsided leaving a black ledge one hundred to one hundred and fifty feet above the present bottom. From this ledge down to the bottom it is black with new lava. There is a sulphur steam jet on the west side. No fire is visible in the daytime, but it can be seen at night. Later in the day there was a heavy breakdown of the western wall, causing the rise of a great cloud of reddish vapor.

Sept. 17, T. M. Chatard says that on the night of the 15th instant there were a number of fire fountains; the hardened crust broke and dissolved, while the lava flows were large enough to show the manner of action.

Whitman Cross, of the United States Geological Survey, has put on record at the Volcano House the behavior of Halemaumau between October 20th and 27th. "On Monday, the 20th instant, there were almost no signs of activity. The lava flow produced by earlier action was recognizable. With a tape line parallel tangents to the circular outline of the crater were drawn, which were 1,500 feet apart, representing the diameter. The depth to the consolidated lava was estimated to be eight hundred and twenty-five feet; and the north-south diameter of the same was five hundred and seventy-five feet. The vertical wall on the south was deeper than upon the opposite side, while in the first case there was a gradual slope to the lava floor, on the other side the slope was higher up and connected two walls. On the north edge

of the lake there was a blow hole or spatter cone about twelve feet high exhibiting two small glowing spots, and sulphurous fumes arose from the cone without noise. October 23d there was a sound of escaping gas from the blow hole, like the sharp puffs of a locomotive getting under headway; they were irregular though often strenuous. At 3 P. M. a part of the top of the cone was blown off, followed by the sound of thrashing and surging lava. At every throb splashes of lava were thrown out of the orifice and the cone grew rapidly. At 3:35 P. M. the whole northwest side of the mound was broken down and a torrent of lava burst out like water from a pipe. The flow was steady with occasional spurts throwing small masses a few feet into the air.

"The lava was liquid, red-hot changing to dull red and black as the crust formed, and as it spread out the domes and ropy lines so characteristic of the general floor of Kilauea made their appearance. By 5 P. M. the flow had covered half of the floor. At 7 P. M. the whole floor was covered and the liquid still continued to gush out; then it decreased and new spatter cones were built up, with orifices by 9 P. M., from which jets of lava were occasionally thrown out.

"The new lava lake exhibited during this evening the common phenomena so often described. Cracks formed in the dull crust, lava pushed out in sheets or tongues, plates of the crust turned up and sunk in the molten lake beneath. The illumination was often brilliant, and all the conditions combined to make the scene grand and impressive. On October 24th there was no flow; the floor was so solidified that fracturing and extrusion of lava was rare and of small extent. At the blow hole there was frequently repeated the process of sealing up the orifice by viscous matter, then a bursting out, making a new hole, which would be sealed up again in an hour or two."

"On the evening of the 25th the strong glow indicated action, and there was another thin flow over the sheet of the 23d. The spatter cone remained on the north side and no other vent could be seen. The action was that of sealing up and bursting again, without any discharge. On the 27th just before daylight a bright glow was noted over Halemaumau, which was occasioned by another thin flow."

The three flows recorded built up the inside mass, perhaps twenty-five feet. He supposes the process of filling up Halemaumau will be continued in a similar manner, unless relief be found by an outbreak of the lava at some lower level, as has often been the case in the past history of the volcano.

In the Hawaiian Gazette for November 18th, appears a further report of the display for a week commencing November 7th.

Friday, November 7: Cone spitting fire only; no flow.

Saturday and Sunday: No change.

Monday, November 10: At 2 A. M. fountain commenced to play.

Tuesday: Today the action is stronger than it has been during the present outbreak; cone blown to pieces, and a geyser spouting fire twenty feet high and about as wide, forming a lake from bank to bank of liquid lava, which is about six hundred feet across: this action continued all day and night.

Wednesday and Thursday, November 12, 13: The action continues as strong as ever, building up the lava lake very rapidly. The lowest floor of the pit has risen one hundred feet since October 20. These were wireless messages from the Volcano House to Mr. Richard Trent.

In the same issue a diagram is given representing the dimensions of the pit, and the amount of the filling since June 1st. The breadth of the pit, 1,500 feet. Depth, June 1, 1,000 feet. Level of the lava October 20, one hundred and seventy-five feet above the bottom. November 13, level of the lava two hundred and seventy-five feet above the bottom, seven hundred and twenty-five feet below the surface of Halemaumau.

From Thrum's Annual for 1903, the report for 1902 is confirmatory of the preceding statements. On the evening of August 25th, lava suddenly appeared in the pit, accompanied by earthquakes of nearly the same date at Hilo. Then it was quiet till September 19th. Another manifestation showed itself October 11th. Measurements proved that the lava had risen one hundred and seventy-five feet since June; the pit in September being eight hundred and sixty feet in depth and about two hundred across. On the night of October 23d three, and occasionally four fountains of lava spouted up from below. November 10th the entire floor of Halemaumau was a mass of molten lava throwing up geyser-like streams.

The Hawaiian Star of March 13, 1903, prints an anonymous statement that there was a manifestation of molten lava about fifty feet wide in the bottom of Halemaumau.

June 21, 1903, Hon. W. R. Castle states that the conditions were very much the same that he saw in 1874, except a filling up by fresh lava for about three hundred feet. Total depth estimated to be seven hundred and fifty to eight hundred feet. He adds: "The time has come when the United States Government might well reserve the whole region of Mokuaweoweo to the sea

at Puna; a long narrow strip to include Kilauea and the line of pit craters; a comparatively worthless tract of country commercially. It should also include the Koa tree moulds at Kuapaawela, where a forest of giant trees was surrounded by a deep flow of later age."

August 23: Clouds of smoke are ascending from the pit. Following this date all was quiet for a long time.

November 25: Halemaumau is in action. There was a glow at 4:15 A. M., when a lake formed, forty by one hundred and twenty-five feet, in the bottom of the crater. Fountains of fire showed themselves, and the other phenomena customarily observable in their company. Remained active till Jan. 10, 1904.

In 1903 a new survey of Kilauea was made under the auspices of the Bishop Museum. A relief of the volcano upon the scale of one hundred and thirty feet to the inch has been prepared by William Alanson Bryan and placed on exhibition. It is the most effective illustration of the volcano ever displayed; and it is understood that the earlier survey of Dr. Brigham in 1865 was found to be accurate. The explanatory text represents that the complete area of Kilauea as portrayed in the relief amounts to 2,650 acres; the circumference 7.85 miles; extreme length 15,500 feet or 2.93 miles. The most noticeable change in the representation is the emphatic manifestation of a greater altitude to the east of Kilauea iki. All previous restorations have made the land to fall off towards the sea (makai). The exact figures are not given save as they are embodied in the model.

August 13-17, 1904: Professor G. H. Barton visited the volcano with a company of tourists, and compares the present state of inactivity with the brilliant displays he had seen twenty-two years earlier.

1904: Hon. L. A. Thurston writes thus November 8th: There have been only slight changes since September 12, 1902. Cracks along the outer rim of the pit have widened, and the approaches seem more dangerous than ever before. No fire nor steam appears in the pit, but there is a considerable sulphur vapor from the extreme bottom. A new path has been made around Kilauea iki for which he suggests the name *Echo trail*—for five distinct echoes can be heard from the west bank of Keanakakoi.

THE DISPLAYS IN 1905.

New interest has been manifested in Kilauea in 1905 because of renewed activity. At the opening of the year Halemaumau was a lifeless pit over eight hundred feet deep, whose floor conconsisted of the cooled overflows, last seen November 25, 1903.

February 24th fresh lava appeared on one side near the bottom, flowing down to the lowest point. After four days of display it was covered up by a slide of debris. Fire was again seen March 3d and March 20th. On March 30th several fiery spots were reported. April 18th, at the depth of six hundred and fifty feet, there was special activity; fountains were playing continually accompanied by large volumes of red-hot lava.

May 1, 1905. L. A. Thurston. A blow hole on the north side has flowed out over the bottom of the pit, making a platform five hundred feet in diameter. It was exploding at intervals of several minutes throwing spatter lava thirty to forty feet. The pit has filled a considerable since November, being now five to six hundred feet deep. The southern bank continues to fall in.

The history for the ensuing four months has been an alternation of fiery discharges and a cooling surface. July 24th to 26th, the depth of the pit was estimated by myself to be about six hundred feet. About every third night the displays of fire are exceptionally brilliant. The place of the discharge shifts constantly from one edge to another. Those that I saw were on the north, west and south edges. The latest report given to me was of a brilliant display on the nights of August 12th and 13th.

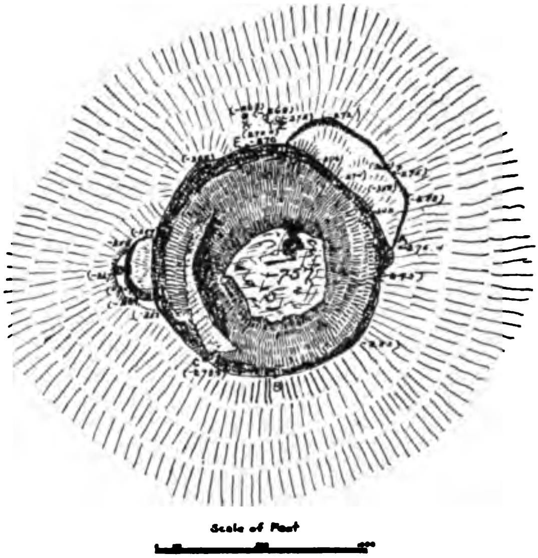
Sept. 18, 1905. L. A. Thurston. Very little change since May 1, except that the pit has filled a little more and the vapor has increased, rising from two cones on the northeast side of the pit. No fire visible nor noise heard in the pit. Bank on southwest side has caved in considerably since May. Smoke very dense, light brown in color, with very little sulphur.

I find in the Hawaiian Gazette for March 13, 1906, the following:

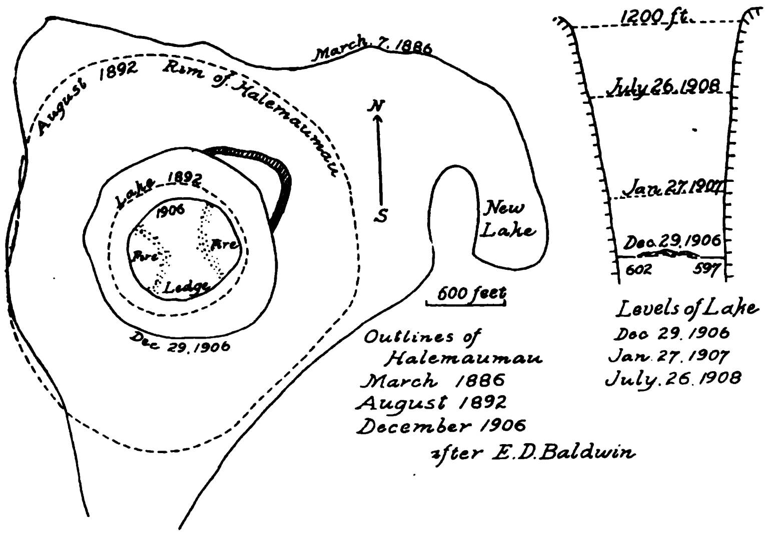
The fires of Kilauea are still in evidence (by wireless telegraph). Volcano House, March 12. Last night our party sat on the edge of Kilauea, fascinated by the display of fire which burned for hours. Mr. and Mrs. Waddell, Edna Lloyd.

Dec. 2, 1906, fire appears in Halemaumau. E. D. Baldwin reports two small lakes, mostly cooled over, the one six hundred and two and the other five hundred and ninety-seven feet below the edge of the pit. Near the center of the western lake a small cone sputtered lava occasionally, with loud reports of escaping steam, which at times sounded like rifle shots. The surface would crack, and considerable lava flow out. The action in the east lake was much the same. There was no sputtering cone, but steam escaped under the east bank with noisy outbursts. The smaller spot to the south is nearly cool.

PLATE 44.



A. Plan of the cone of Halemaumau.



B. Plan of Halemaumau, December, 1906.

KILAUEA IN 1907.

Jan. 27, 1907, F. S. Dodge reports that the lava had filled up the pit to the level of four hundred and fifty feet from the top, occupying an area of nine acres. Plate 44B is copied from a plan made by E. D. Baldwin, Dec. 26, 1906, showing the appearances then visible, and the relative positions of Halemaumau in 1886, 1892 and 1906. And upon one side the pit of Dec. 2, with its two lakes, the filling up to four hundred and fifty feet, Jan. 27, 1907, and up to one hundred and ninety feet as seen July 26, 1908.

Hon. L. A. Thurston spent a month in Hawaii, and under date of April 23, reports as follows in the *Hawaiian Gazette* concerning the volcano:

I visited the crater three times. It is more active than it has been at any time since the formation of the present pit in July, 1894. The pit has filled to within about three hundred and fifty feet of the top. There is a molten lake about four hundred feet long by two hundred feet wide. During the interval between 11 A. M. and 3 P. M. one day, about ten days ago, this lake overflowed its banks bodily, three times, the congealed lava crust being swept over the banks in a crimson flood, the surface of the lake rising and overflowing in a mass approximately one hundred feet wide. In addition to this there were from two to ten molten lava flows continuously issuing from the banks and flowing to the lower portion of the pit. At the present rate of filling, the Halemaumau pit, which was nearly a thousand feet deep three years ago, will be filled within the year, and the condition which existed in 1894, a molten lake higher than the surrounding country, will be repeated.

May 21st and 22d, the volcano was inspected by the Congressional party which visited the Islands under the auspices of the Territorial Government. Twenty-eight members of Congress with their friends had accepted the hospitalities of the islands. Pele was in one of her quiescent moods, but the scene was impressive and grand enough to satisfy their anticipations. A novel experience consisted in the serving of a dinner to the visitors where toothsome viands had been cooked by the heat supplied from the depths. After the dinner the health of Madame Pele was proposed by Hon. L. A. Thurston, who recited the legend and described the varied vagaries of the volcano. The numerous citations in this book from Mr. Thurston's statements prove that no one could better narrate the history of the volcano than he.

May 28. Demosthenes Lycurgus reports signs of fire, which increased by July 10 to be a lake of fire boiling furiously seventy-

five by seventy-five feet. It rose over the pit floor and flowed down in a cataract. Continued to rise and fall every twenty-five minutes.

July 12. F. M. Wetmore saw two lava flows ,three active fountains and a cone sending out a flame like a Roman candle.

Aug. 29. "It is the pit of hell," I said. "Yes," said Cartwright, "it is the pit of hell. Let us go down." "And we went down."—Jack London.

THE RENEWED ACTIVITY OF 1908.

Nov. 30, 1907. Lycurgus says, "Volcano active again after a quiet of seven months. A little cone with flame issuing. Was not persistent."

Dec. 7, 1907. W. A. Wall figures the black ledge at the depth of four hundred and fifty feet, the lower pit two hundred feet wide at the top, and fire eighty feet below.

February, 1908. Cone emitting fire. Florence Gurney.

March 20. C. N. Towle pictures streams of lava flowing in both directions from a cone, till they meet on the opposite side.

March 17-25. J. W. Waldron. Pit three hundred feet deep, 1,800 feet across. Cone in northwest corner spouting noisily.

19th. Cone blew off its top and threw out lava.

20th. Cone blows off again, and river of lava flowed around the edge of the bottom.

21st. Large flow from the fractured cone.

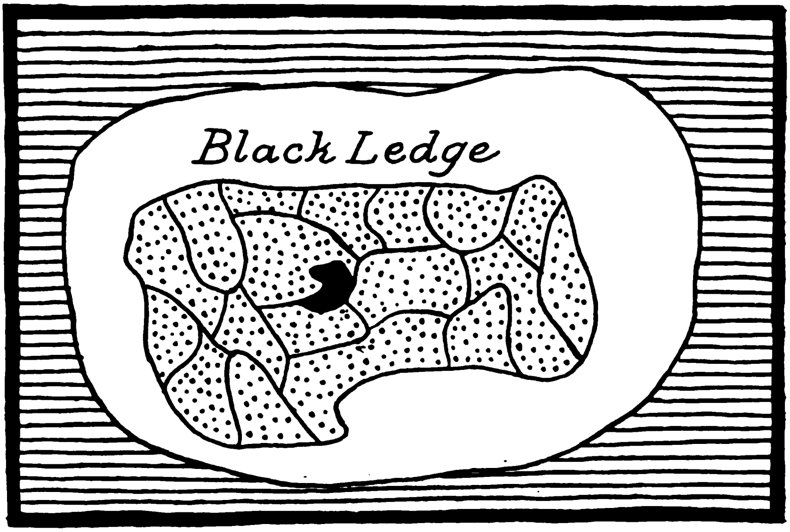
April 18. G. W. Kinkaldy. Cone thirty feet high with three orifices sending off spray and lava; sounds like musketry. Lake traversed by red lines.

April 25. E. S. Aldrich. Bottom of pit risen to one hundred and fifty feet. Agitated by whirlpools of flowing lava and fountains seventy-five feet high.

May 26. L. A. Thurston estimates the pit to be two hundred feet deep. Lake eight hundred by four hundred feet, shape of figure eight with a crescent shaped island. More activity than at the breakdown of March 11, 1894. The island seventy-five feet long. After each outburst of gas a tremendous suction draws lava from a radius of one hundred feet into a maelstrom; cakes of lava fifteen to twenty feet in diameter turned upon edge and disappearing. A great spring to the north pours out lava copiously. Lake enlarging constantly. Glare visible from Hilo and Honuapo.

June 20. Visit of Secretary Garfield. More than one hundred persons in the party.

June 21. The same depth as on May 26, but the lake is fifty per cent. larger.



A. Rough Plan of Fire Lake in August, 1908.

B. Photographic View of the same.

July 14. Rev. W. S. Westervelt says the boiling pit has filled up from twenty to twenty-five feet in the previous fortnight.

July 26. E .D. Baldwin. It is one hundred and ninety feet down to the lake from the edge of the pit. See Plate 44B.

July 31. Fire in three-fourths of the pit of Halemaumau. Eight large fountains.

Mr. C. L. Rhodes has described very graphically what he saw August 13 to 15. The molten lava has accumulated in the large pit from one thousand to about one hundred and fifty feet below the rim, a liquid conical column, broadest at the base. The fountain of supply is from Old Faithful, a small area near the north side. About a third of the surface is never blackened over. This lava has been building up a wall around itself, which on the 13th inst. was fifteen feet higher than the outer zone of the liquid, so that the lake might be compared to an inverted saucer. At length the lateral pressure overcame the strength of the wall, and the lava flowed out in great streams until it tended to even up the surface. The lava may sometimes be higher at its border than it is nearer the center.

Plate 46 shows a rough plan and photograph of the lava, as seen in August.

August 18. N. B. Emerson. The fire-pit bounded by a vertical wall two hundred feet high; 1,000-1,200 feet in diameter. Fire-lake occupies from one-half to two-thirds of the pit, bordered by a sloping black ledge between it and the walls. Lake usually covered by scales of dark lava traversed by many fire lines, not clear cut, but jagged like fish bones. *Fire Fountains*. "Old Faithful" described. A jet of red lava appears; scales are sucked down around it. This swells up as one huge rotund white hot mass leaping high up into the air for many seconds, and then subsides as if there were a connection with a fire-shaft deep into the earth's interior. This is in the northeast part of the lake. There are others in the northern quarter and near the edge, never so large as Old Faithful. Fire-lines suggest the arms of Octopus. Fire-caves or ovens on the west side. Action like surf breaking upon the side of a cliff, somewhat rythmic. Movement from west to east. In 1881 there were three fire-lakes and a correspondingly greater action.

August 20. W. D. Alexander had seen Halemaumau when it was an abyss 1,000 feet deep and 1,200 feet wide, pouring out volumes of black smoke; now there is the breaking down of the retaining walls of the inner lake in three places from which cascades of liquid fire are falling and flowing till the whole space is filled up to the level of the inner lake.

Aug. 26 to Sept. 6. Conditions described by Dr. W. T. Brigham in *Thrum's Annual* for 1909. The present floor of Kilauea is now about four hundred feet higher than in 1864. The Halemaumau pit had filled up to within one hundred feet of the rim or fifty feet above the lower edge of the dome.

Thursday, Sept. 4, in the early afternoon the fountains ceased to play and the subsidence of the pool began. With Messrs. C. B. Thompson and C. N. Forbes, Dr. Brigham went to Halemaumau soon after dark and found that the lake had fallen about a hundred feet. "In the center of the pit was a curious break running E. to W., at the edge of which was a vertical slab of lava semi-circular in form, resembling half a mill-stone, and other slabs continued the wall for some distance. Over these fell a cascade of lava in a condition I had never seen before; its particles seemed to be in a state of repulsion, and although white hot fell through the central hole of the 'mill-stone' as meal. There seemed absolutely no cohesion, no signs of plastic molten lava."

Mr. G. H. Fairchild describes the collapse as follows, the whole process of the emptying taking about two hours time. "On Thursday night the level of the lava had reached a point less than a hundred feet, I should judge, below the level of the main crater floor. Old Faithful spouted its fiery flow to a height of twenty feet, and from the edges of the lake a score of lesser fire-fountains were playing continuously. At midnight there was a strange motion in the lava, which began suddenly to sink in towards the center. The sinking continued till the whole pit was a maelstrom of fire and a chasm appeared in the lava lake. Like liquid pouring into a funnel, or like the waters swirling out of a bath tub after the plug is drawn, the boiling lava began to pour in cataracts of fire into the chasm. From all sides the lava flowed, and as the torrents drained away into the depths, the sides of the crater, gleaming red, began to crash into the lake, splashing the lava like surf into the air, while the dull roar of the crumbling rock and the sharper detonation as the colder rocks heated and exploded was terrifying but yet absorbing.

"As the great slabs of lava peeled off the sides, pieces hundreds and thousands of tons at a time, the levels streamed out cascades of liquid lava, which hung and cooled about the sides like great golden stalactites. Deeper and deeper the lava sucked into the depths and on Saturday morning the pit was dead. Everything that had filled it with the bubbling, spurting lava for nearly a thousand feet had drained off in the opening

far below and there was nothing to be seen in the depths of Halemaumau but a cloud of smoke. All the fire had gone."

Sept. 6, at 11 P. M., a spark of fire appeared five hundred feet down, and lava increased for two hours, when the lake was only one hundred and fifty feet lower than before the collapse. J. A. Kennedy.

"The fire increased very rapidly, astonishingly so. It spread in area, and so quickly that we could see it was rising, apparently being forced up by some great power beneath. This force seemed to push the lava into a cone that would burst with a noise, shooting the flame higher and higher. It continued in this way, the fire coming nearer and the cones forming and bursting one after another. There appeared at one time to be three cones of fire that merged into one; and again, when the force beneath must have been more intense the flame shot fully two hundred feet into the air like a rocket, then gradually spread out into the shape of a fan."

L. A. Thurston writes, "The lava was rising rapidly. All at once it quit rising. A red line showed around the border; masses of cooled lava broke off and fell into the liquid. These falls and rises vary from ten to fifty feet. There is an artesian flow on one side. When the lava lake is low a stream comes from this orifice. When the lava rises above this stream it becomes a fountain pushing upwards."

There was an earthquake at Hilo and in Puna about noon of Sept. 2. Another at 6:15 P. M., Sept. 4. A third, at 6:15 P. M. Sept. 5, the most severe of all. Sept. 6 a slight one. The shocks were unusually severe. Those who experienced the shake-up of 1868 believed these were equal to those. Great damage was done in Hilo to china and earthenware. The shocks were heavier in Puna than in Hilo.

The near coincidence of these earthquakes with the first discharge of the lava from Halemaumau leads us to believe that the two phenomena were genetically connected with each other, rather than to some general cosmic influence.

Oct. 2 to 11. E. E. Paxton reports that the lava was rising in Halemaumau when he left; it had risen fifty feet during his visit; and is from one hundred and fifty to two hundred feet below the top.

W. A. Bryan, Sept. 17. The lake estimated to be nine hundred feet across with fourteen fountains. Liquid lava thrown up two hundred and fifty feet, even above the border of the pit. In October, '02, he had found the lake to be five hundred and twenty-five feet below the surface. Since then there have been

land slides in Kilauea. Along the eastern side the old observation point has disappeared. A strip of rock sixty feet long caved in a few days after his model of the volcano had been completed.

Oct. 17. Harry Dennison measured the depth of the lake with a string. Two hundred and twenty feet were recorded, and he estimated the balance of the distance at from fifty to one hundred feet.

Oct. 18. Old Faithful was active eighteen times in ten minutes. On the 21st it was twelve times in ten minutes; and again eighteen times in ten minutes.

KILAUEA IN DECEMBER, 1908.

The conditions at Kilauea in the early part of December were examined by myself in company with Mr. Thurston, who writes as follows, under date of Dec. 6:

"No radical change since last September and October. The surface has subsided somewhat, being now three hundred feet deep. No indication of rising or falling seen. The welling of the lava as voluminous as ever. Action less spectacular than in September. Chief action on northwest side, where there was continuous boiling over an area one hundred by one hundred and fifty feet; lava being spattered up ten to twenty-five feet. A tremendous suction adjacent to the boiling area, moving as much as five miles an hour. Three black ledges, the innermost from fifty to sixty feet high."

There was no change in conditions from Dec. 3 to 11. The length of the lake was estimated to be three hundred and fifty feet and half as wide. Occasionally the lava would flow in from a hole on the northerly side. Much of the surface was darker because of its congelation; thus various fire lines would make a network, the pieces would be disjointed and sink out of sight. The spatter work reminded one of gold leaf. Except that the level of the lake was lower than it was early in September there was no essential change in the conditions, as described above. Pele's hair was plenty.

The general features of the Caldera may be mentioned. A carriage road has been constructed from the Volcano House to the south side of Kilauea-iki, a distance of four miles. The government has furnished a number of convicts from the penitentiary who are engaged in the necessary digging, grading and removal of the earth. It is intended that this road shall soon be completed as far as to Keanakakoi, and thence directly to Halemaumau across the sulphur banks, so that visitors may

ride in carriages to the very brink of the fire; and eventually it will be possible to ride entirely around the Caldera. It is evident that there have been several slides of rock into the pit, so that the area of the volcano is constantly growing larger, though not enough to be noticeable upon our maps of small scale.

A few altitudes are presented:

	Above the Sea	Below Volcano House	Below Uwekahuna
Volcano House	4040	...	117
Waldron's Ledge	4030	10	127
Kilauea-iki, north side	3922	118	235
Kilauea-iki, bottom	3173	867	984
Poli-o-Keawe	2932	108	225
Keanakakoi, edge	3757	283	400
Keanakakoi, bottom	3357	683	800
Kapuai	3719	321	438
Puu Pohaku, heights south of Kilauea	3879	161	278
Lowest level of this divide	3765	275	392
Uwekahuna	4157	+117	...
Wilkes' camp	3970	70	187
Black ledge, lowest point in path under Volcano House	3556	484	601
Edge of Halemaumau	3758-3772	268-282	385-399
Bottom of Halemaumau Dec. 6	3460	580	697
Little Beggar	3702	338	455
Height of cone of Halemaumau	202-216	...	...

Viewed from above the black rock is very suggestive of ink. On reaching the floor the roughnesses are seen at their proper dimensions, comparable to waves on the ocean. A well marked trail leads to Halemaumau, traversed constantly by tourists on foot or horseback. Quite near the starting point is a large fissure spanned by a bridge, as much as a fourth of a mile in length, crossing the path and rudely parallel to the north wall. To the left are many hollow domes from one to three hundred feet long and perhaps twenty feet high, lined with stalactites. These were once liquid lava flowing northerly from Halemaumau. These hummocks and the whole surface are traversed by fissures, produced by the falling of the roofs of these tunnels, and often these clefts have been occupied by streams of lava. The floor is an immense black ledge, mostly pahoehoe, and having much ropy structure. Next the

east wall the waves are smoother and broader. The flow from Poli-o-Keawe of 1832 is hardly recognizable, having suffered from slides, and also has been obscured by vegetation. Rather towards Uwekahuna are black lines of aa. Near the corral for horses may be seen the flow of the Little Beggar, a sunken tunnel with five flows of petrified lava, films and incrustations of gypsum. To the west are areas from which hot gases arise, as the Devil's Kitchen, where food may be cooked and postal cards scorched. Near the view point of the melted lava are the remnants of three spiracles. Halemaumau is surrounded by the finest exhibitions of the domes, tunnels, and ropy structure, being largely the flow of 1894.

The guides can find caves filled with stalactites to the south, where fine specimens may be obtained. There are also places where sulphur has been condensed from the vapors.

When the lava was fresh there were various grades of liquidity; the thinnest being where the heat was most intense, and the surface had a beautiful black glaze, sometimes called hyalophane.

The sulphur banks in the southwest part of the Caldera seem to consist of tuff dipping gently towards Halemaumau. There are several rents upon it running N. E. and S. W., seemingly the work of recent faulting. Steam rises after rains, from the east side of Kilauea between the sulphur banks and the 1832 flow. The basalts succeed the tuffs at the mouth of the canyon leading from Keanakakoi, with a horizontal stratification. A similar consolidated tuff borders the volcano opposite Halemaumau, and Puu Pohaku is covered by much basaltic pumice.

Early in February, 1909, E. D. Baldwin finds the level of the liquid lava to be two hundred and thirty-five feet below the edge of Halemaumau.

HALEMAUMAU.

Halemaumau is alwavs the place where the fire is to be seen. It might be called the core or nucleus of the volcano. While the pools of lava may appear elsewhere when the discharges are profuse, the fire will be seen only at the bottom of the pit when it is nearly extinct. The number of the lakes is variable. When it exceeds unity it is not easy to select the particular one which represents the chief avenue of the flow. As a matter of convenience I will present a resume of the history of these lakes of molten lava. The earliest account is rather indefinite. In 1825 Mr. Stewart is more precise.

1825—Size of lake, 1 mile wide; observer, C. S. Stewart.
1838—3,000 by 1,000 feet; W. P. Alexander.
1834—3,570 by 2,100 and 657 feet in diameter; D. Douglas.
1838—Five 12,000 square feet each, one of a million square feet; Count Strzelecki.
1839—One by one-half mile; John Shepherd.
1840—1,500 by 1,000 feet; Captain Wilkes.
1846—2,400 by 2,000 feet; Rev. C. S. Lyman.
1848—No fire; T. Coan.
1849—Size of lake not stated; T. Coan.
1855—400 by 250 feet; T. M. Coan.
1857—500 feet in diameter; T. Coan.
1862—600 feet in diameter; T. Coan.
1864—800 feet in diameter; W. T. Brigham.
1865—1,000 feet in diameter; W. T. Brigham.
1866—Flood of lava two miles long; T. Coan.
1867—Eight lakes; A. F. Judd.
1868—Twelve lakes just before eruption; C. E. Stackpole.
1868—3,000 by 1,500 feet, no lava after eruption; T. Coan.
1869—Three lakes; H. Bingham 2d.
1870—Variable.
1871—Variable.
1872—Two lakes; D. H. Hitchcock.
1873—Two lakes each 500 feet in diameter; Charles Nordhoff.
1874—Four lakes, largest 600 feet; J. W. Nichols.
1874—Four. Southern called Halemaumau, 300 feet. Lake Kilauea, 800 feet. A third 500-600 feet diameter; H. M. Whitney.
1875—Four lakes; Challenger Expedition.
1878—Halemaumau, 400 by 100. Lake Kilauea too hot to be approached; C. J. Lyons.
1879—Lakes disappeared in April, two in July; W. H. Lentz.
1880—Halemaumau, 400 feet broad and ten others; Rev. J. M. Alexander.
—Four lakes, average length 1,000 feet; W. T. Brigham.
1881—Four lakes; W. W. Hall.
1882—New lake, 480 by 300 feet. Halemaumau, 1,000 by 600; C. E. Dutton.
1883—No changes; C. H. Hitchcock.
1884—Both lakes enlarged; W. R. Castle.
1886—Lakes unusually full just before breakdown; E. P. Baker.
1888—Central pit, Dana lake and small pools. Conditions the same as in 1886; F. S. Dodge.

1894—Highest lake in whole history, 800 by 1,200 feet; L. A. Thurston.

1907—Return of molten lava after long periods of slight activity, 400 by 800 feet; L. A. Thurston.

IS HALEMAUMAU A FIXTURE?

Mr. A. B. Loebenstein of Hilo, is reported in the Washington Post of Feb. 6, 1906, as saying that Halemaumau has moved south 1,783 feet during the past thirty years. In 1873 when surveys were made in connection with the leasing of the land, this crater stood within the area of Keauhou, the boundary line passing through its center. Thirty years later a new survey was made which proved that the floor of the crater had crossed the boundary line into Kapapala. "It should be understood," he says, "that the inner crater of Halemaumau has not disappeared in one place and broken out in a new spot, but that it has worked itself along the floor of the outer crater foot by foot for a third of a mile."

These remarks were made in connection with a suggestion that the Government should take possession of the volcano and its surroundings for a National Park. Incidentally it may be a question of ownership, and concerning that we have the reported remarks of Mr. F. S. Dodge, Superintendent of the Bishop estate. "The shifting of the lake of fire does not invalidate any claim we may have on it. The line of the Bishop estate is tied to the center of the lake, and our boundaries move along with it. The description of the boundary shows that the line runs from well known points on the bluff 'to the center of the lake of fire,' and it is a well recognized fact in the Territorial Courts that a recognizable fixed point has precedence over distances and bearings. Thus, no matter where the lake of fire may wander to, it drags our line along with it."

HOUSES OF ENTERTAINMENT FOR VISITORS.

The first one mentioned was situated upon the Malden plateau in 1824, for the accommodation of the Princess Kapiolani and her retinue. It was a simple native hut, and was found to be very convenient for the use of Lord Byron's party in 1825.

In 1840 Captain Wilkes' party encamped upon the low ground between the sulphur banks and the volcano. Mr. Goodale says that in 1847 he slept in an old shed; in 1856 he found a house but no host. Other early visitors represent this place of accommodation as a grass house consisting of one room with a coarse hala mat upon the earth floor. Travelers brought their provisions and

A. Volcano House, 1868.

B. Volcano House, 1872.

used for drink the water that was condensed from steam. In Plate 47AB may be seen two of the early houses, perhaps in 1868 and 1872, supposed to be situated upon the site of the present Volcano House. In 1865 this house had become sufficiently durable to allow the keeping of a record book. About this time the industry of gathering the pulu from the tree ferns to be used as the filling of mattresses was quite flourishing, and the house accommodated both the visitors and the pulu gatherers. Judge L. Kaina and G. W. C. Jones were associated together in this business in the sixties and seventies, and the house seems to have been of this primitive character.

Upon June 6, 1877, W. H. Lentz was employed to assist in building a better house, using boards and timbers. He succeeded to the position of landlord and remained in charge till April, 1883. Messrs. Jordan and Shipman were in charge for the next two years. June 20, 1885, the property passed into the hands of the Wilder Steamship Company, with J. H. Maby for manager.

There was a new organization April 1, 1891, called the Volcano House Company: W. R. Castle, president; Peter Lee, manager. Extensive additions were made to the house.

In 1901 there were further additions to the buildings. Fred Waldron succeeded Mr. Lee as manager.

St. Clair Bidgood was the manager in 1903.

George Lycurgus was next elected manager, succeeded at the end of 1904 by Demosthenes Lycurgus, the present head, who is also the chief owner of the stock of the company.

Plate 15 represents the Volcano House as it appears today.

PART IV.

The Hawaiian Type of Volcanic Action.

If one should attempt to classify volcanoes he must take into account their history, geographical position, petrographical character of the lavas emitted and other products, the variable fusibility of the flows, their styles of eruption, shapes of the mountain built up, descriptions of the several sorts of craters, and other matters. It will not be convenient for us to consider any general classification, but we will simply state what features of form, history and style of eruption are characteristic of the Hawaiian volcanoes, with occasional allusions to what may be seen elsewhere, by way of contrast. The details presented in Parts II and III will furnish illustrations of the several phases of action.

At the outset it will be proper to state that upon the Island of Hawaii there are five great volcanoes; the Kohala region and Mauna Kea, both now extinct; Hualalai, Mauna Loa and Kilauea. Our studies have been confined chiefly to the last two, because their activities appeal to us. The investigations into the histories of the others would suggest what might be termed *post mortem* examinations. Each of these volcanoes may be said to have its own sphere of activity. Some authors regard Kilauea as an appendage of Mauna Loa. It seems best to us to regard them as thoroughly distinct above the sea level, though we expect to show that they may be one deep down. Mauna Loa extends to the bases of Hualalai and Mauna Kea upon the northeast and northwest. Upon the south it probably includes the south point of the island as far east as Punaluu; thence the southern edge may be traced nearly along the road through Pahala and the Halfway House to the lowest depression between Uwekahuna and the slope of the greater mountain. From thence we conceive it to continue along the same general direction to the bottom of the slope near the saw mill erected to cut the koa lumber, two miles northeast from the Volcano House. The impression prevails that there is a considerable elevation to the north of the sulphur banks which has been called Mount Kilauea. To my eye there is a plateau scarcely exceeding the height of the carriage road from the Volcano House towards Glenwood for two or three miles, consisting of the flat basalts of Kilauea, covered by the dark ashes thrown out by explosive eruptions. There seems to have been a flow of

lava from some two or three miles east of Kilauea east and northeast, marked by the absence of trees, and therefore corresponding to the line of the trail from Olaa to the volcano in use before the construction of the carriage road. This may be followed to Pahoa, sixteen miles from Hilo. Whatever lies north of this flow seems to belong to Mauna Loa, and everything to the south to be embraced within the sphere of influence of Kilauea. The projection of land at Leleiwi, southeast of Hilo, nearly ten miles wide, would seem to belong to some ancient flow from Mauna Loa. The Kilauea area would commence at a point at Punaluu, expand to thirteen miles width between the koa mill and Keauhou, and to retain about this same width to Cape Kumukahi.

There is a bend of the line of activity from Keanakakoi southeast on the road to Puna, and thence northeasterly near the line of the flow of 1840: and it is possible that the area designated above as belonging to Kilauea may lose a portion of itself when the country has been better explored. That there is a line of heat as far as to the Eel's Eye and beyond is very evident. To the south from near Kalapana to the end of the flow of 1823, two or three miles mauka from the coast is a pali more than twenty miles long and often several hundred feet high, on the makai side of which the land has been depressed by faulting. There is a constant tendency to submergence along this coast, as shown at Kalapana in 1868, and it is claimed that there was a slight depression near Pohoiki manifested at the earthquake of September, 1908.

A further indication of the distinctions between the Mauna Loa and Kilauea spheres of activity is suggested by the differences in the temperatures of the spring waters between Punaluu and Puna as stated by Mr. Guppy. See page 132. The warmer waters suggest the influence of Kilauea, while the colder temperatures are in the area of Mauna Loa.

THE ORDINARY WORK OF THE VOLCANOES.

For most of the time the activity of the volcanoes is rather commonplace. There is a daily routine of work much like respiration and assimilation in the human body, partly illustrative of a kind of life and partly a preparation for eruptions. The most prominent feature is the presence of lakes of liquid lava, which emit heat and vapors and throw up jets. The surfaces are crusted over and the congealed layer breaks up into irregular blocks which sink and disappear. Fumes of sulphur and aqueous vapors arise from the caldrons, causing visitors to avoid their leeward sides. What may be termed smoke mixed with the vapors will develop clouds overhead or rise in columns spreading out like

the branches of trees or an opened umbrella. Many instances have been cited of the presence of these clouds over Mokuaweoweo, some of them being charged with fine cindery particles and others not to be distinguished from cumulus clouds formed by the precipitation of vapors in a colder region. The tree is evidently an attenuated variety of the copious discharges in times of great activity.

The ebullition is constant. Certain portions in their efforts to rise as bubbles do projectile work, accompanied by noises. The jets spout upwards as much as thirty feet and the action is rythmical. Some speak of these jets as dancing joyously with many variations of height and position. The spiracles are where the melted matter solidifies drop by drop as it is thrown up. The jets are more numerous along the borders because the heat escapes more quickly in the center and thus is cooler.

The Pele's hair, where the flying drops are pulled out into long threads is another instance of projectile action. The knotted parts may inclose crystals.

There seems to be a constant supply of the igneous material, so that the lakes overflow. At first the cooling of the overflow builds up a dome or column. Then the streams flow like rivers all over the floor, perhaps cascading, till the pit is filled up, and then meandering into all the low spaces. Since 1823 the cone of Halemaumau has been built up as much as six hundred feet. The vapors are mostly steam, sulphurous acid, a little carbonic acid, hydrogen and atmospheric air.

The source of the water has been referred to rain, the ocean and the original magma of the interior. The rainfall in the eastern part of Hawaii is excessive, reaching to two hundred inches a year at Hilo, and it is rarely the case that visitors fail to receive a good drenching. Because the volcanoes are insular the ocean is not far away; and it is believed commonly that the seawater gains access to the interior fires for the eruptions, if not for the constant requisite supply. In Vesuvius the entrance of seawater with its dissolved sodium chloride may explain the presence of so much sal-ammoniac and copper chloride among its minerals. Traces of them have been reported for Kilauea, but I have never been able to find any material token of their presence. Hydrochloric acid is so pungent that it could not fail to be detected, if present. Possibly the bright red saffron and orange spots among the lavas may have been produced by the conversion of iron chlorid into ferric oxide; but if there is iron chlorid in the lava brought from the ocean, why should not the other chlorids be present?

Vesiculation is justly appealed to as evidence of the presence of water or steam. Professor Dana has fully discussed the matter. He describes five styles of it.

1. The ordinary lava stream of the floor, where the vesicles are oblong and constitute from one to fifty or sixty per cent. of the rock.

2. The common spherically vesiculated lava where the bubbles are too small to be elongated by the flow and constitute from thirty to sixty per cent. of the mass. Such lava is common upon the flows of 1880 from Mauna Loa near Hilo. It may not extend downwards more than twelve feet.

3. Glassy scoria in various parts of Kilauea, the scum of the lava, which is often troublesome because one breaks through it in walking. It is easily fusible and the vesicles constitute sixty-five to seventy-five per cent. of the mass.

4. Ordinary scoria, common about cinder cones of stony texture. The vesicles constitute sixty to ninety-five per cent. of the mass.

5. Spongy thread lace scoria, existing as a layer a foot thick over the southwest part of Kilauea. The vesicles are very coarse and constitute ninety-eight to ninety-nine per cent. of the mass. They are polygonal with twelve and fourteen sides and frequently distorted by pressure. Some of the holes are half a cubic inch in bulk.

Very little water is required for most of this vesiculation; no more than that of molecular diffusion. When a specimen containing forty per cent. of vesicles has its specific gravity determined and compared with that of the same material solid, it is found to be as 1.88 to 2.98. The required water is hence .0003 per cent. of the bulk or .0001 of the weight of the mass. The amount of moisture required to produce the vesiculation of the thread lace scoria was determined to be 3.125 per cent. of the bulk or 1.1 per cent. by weight.

Some have conceived that the downward ingress of water would be checked violently by the intense heat at great depths. The best authors do not accept that view; partly because when the temperature of the critical point of water (773° F.) is reached, dissociation takes place, and there may be an attraction rather than a repulsion. The absorption of the water will increase the bulk of the lava, so that there will be a greater pressure in the lower part of the conduit, perhaps enough to force the material to the surface: and thus vesiculation may be an important element in producing projectile results.

It has been noticed repeatedly that the liquid lava enlarges its

area by dissolving its retaining walls. Floating islands and debris cones have also disappeared; and it is a question whether the greater part of the calderas have not been enlarged in this way. Heated silicates possess greater powers of dissolving refractory substances, especially when under pressure; but this opens too large a subject to be discussed here.

THE ASCENSIVE ACTION IN THE LAVA COLUMN.

Perhaps the first suggestion of the uplifting action came from Prof. C. S. Lyman in 1846, following observations two years earlier by Mr. Coan. In 1844 Mr. Coan found that the lower pit formed in 1840 had been filled up, ostensibly by overflows of lava. Two years later (June, 1846) this pit was nearly obliterated, and there were wide canals of liquid lava intervening between the black ledge and the area of the lower pit. By July, 1846, the pit was filled up and Mr. Lyman concluded that the interior had been elevated, in some parts above the black ledge, which had remained stationary. When the pit was depressed many blocks of lava had fallen into it, making a talus on the floor after elevation. These fragments formed a ridge inside of the canal (shown in Plate 30) higher than the black ledge from which the blocks had fallen. This phenomenon he attributed to the "combined effect of repeated overflowing together with the upheaving agency of subterranean forces." Mr. Coan subsequently noted further movements in the same direction.

In 1848 Mr. Coan describes the formation of a crust over the lake of Halemaumau, which was soon raised into a dome two or three hundred feet high from which one could look out upon the surrounding country beyond the outer wall. This dome was said to have been "formed by the compound action of upheaving forces from beneath, and of eruptions from the openings forming successive layers upon its external surface." This dome collapsed in 1855.

Meanwhile the interior area continued to rise, and streams of lava to flow over the black ledge adjacent to the walls, while the original talus of 1846 is discernible upon the map of Mr. Brigham made in 1866. It was very nearly a plain in 1868 when two-thirds of the floor fell down as much as six hundred feet, leaving a lower pit comparable with that figured by Drayton in 1840, and a black ledge encircling the outer walls a hundred feet higher. Thus the removal of the subterranean support of the mass that had been slowly rising for thirty-eight years caused the disappearance of the columnar block.

The subsequent filling of the lower pit till the breakdown of 1886 was mostly effected by flows from Halemaumau, but the "crag walls" and circular debris about the principal lake up to two hundred feet altitude are to be ascribed to the ascensive column.

Three months after this collapse, the cone within Halemaumau began to rise. Several figures illustrate these changes. The level upon March 6 was three hundred and eighty feet below the datum point at the Volcano House, the highest point attained by the black ledge thus far in the history of Kilauea. (For convenience the figures showing the variations in the altitude of the ascensive column are calculated as below this datum, with the minus sign.) March 7 the lowest point of the depression was nine hundred feet. See the sections 1 and 2 in Plate 38. The beginning of the rise was more rapid than it was later, viz., one foot per day. In October, 1886, Plates 37B and 38, the depression had been filled up, in some measure by lava flowing. but more particularly by elevation of the debris to be on a level with the rim of Halemaumau—three hundred and thirty-five feet. Professor Dana saw the cone in August, 1887, and declared it to be rising slowly. In July, 1888, by Mr. Dodge's measurements, Plates 38, 39A, the highest point was one hundred and sixty-two feet. There are no measurements to indicate how much the cone rose later, for nearly a year. In May, 1889, the floor and the cone fell eighty feet. But it commenced to rise again till the highest point was attained of about eighty-five feet, just before the collapse of March 1, 1891. The horizontal outline of this column, or of Halemaumau, is shown in Plate 43 in its relation to the earlier outline of 1886. The falling of the floor to nearly five hundred and fifty feet indicates how much the ascensive column was depressed.

After this depression the refilling of the pit was occasioned chiefly by the accumulation of lava; but on March 21, 1894, there was a sudden elevation of the north wall to the extent of eighty feet, which must be referred to another ascensive movement, though it does not seem to have been very important, as it had mostly disappeared before the collapse of July 8 to 11 following.

The presence of fault planes parallel to the outer wall of the caldera or to Halemaumau as seen on the map of 1865, or to the outline of Kilauea iki, would suggest some relation to ascensive columns. Hence a careful study will tend to increase the number of these columns in all the calderas. They illustrate also the sympathy discernible between the volcanoes.

A column of basaltic material rising between circular walls reminds one of the obelisk or spine forced upwards in the late eruptions from Mont Pelée in Martinique and at Bogosloff in

Alaska. These were not permanent because of exposure to denudation; but if they had been protected like the ascensive columns in Kilauea, they might have endured much longer. It is conceivable that the spine may sometimes be elevated from one side as a horizontal block, so as to be like the elongated rectangular mountains now projecting above the floor of Mohokea. They may bear kinship also to laccoliths.

The force that elevates these columns must be the pressure of the deep seated mobile lava seeking an outlet, and of course intimately related to the general theory of volcanic action. Some have spoken of this action in Kilauea as if the column were floating on the surface of the subjacent lava. When more lava is supplied the column rises; and after the removal of the liquid the debris will sink back, following it downwards as far as possible.

ERUPTIONS.

The ordinary work of the volcanoes is accumulative. The molten lava has been gathering at the apex of the ascensive column in such amount that there is not strength enough in the containing walls to keep it in place, and it flows away down the mountain side, or else disappears in an unseen abyss. As soon as relief is granted by a discharge the volcano is quiet, and the ordinary work is resumed until there is material enough for another eruption. There may be said to be four kinds of eruption: first, those escaping from orifices high up the mountain; second, those emitted from fissures quite low down, accompanied by severe earthquakes; third, those that disappear into the earth, breakdowns or downplunges; fourth, those that are submarine. In Hawaii flows from the surface, or edge, of the calderas, have never been seen in historic times.

Viewed from a different standpoint the eruptions may be quiet or explosive—the first being where the lava flows like water without much commotion: the second where the discharges come out from orifices like cannon from ordnance, scattering projectile fragments. Our eruptions are so commonly of the first class that they have been regarded as representative of the Hawaiian type. But the recorded history has demonstrated, as stated by J. W. Judd, that the "two conditions are presented by the same volcano at different periods, and pass into one another by the most insensible gradations." As has been often intimated, a noise or earthquake shock has usually preceded the eruptions when the observer has been located near the place of outbreak. A person in Hilo could not know by observation whether there was

any disturbance attending the sudden illumination of the sky in Mokuaweoweo forty miles away. Because he hears and feels nothing he assumes that the action is absolutely quiet, but those who happen to be stationed near the outbreak commonly speak of light or heavy earthquakes. So it has seemed to me probable that earthquakes accompany every outbreak of the first class. The presence of fragmental materials and heated vapors in the discharges from Kilauea in 1400 and 1790 indicate eruptions as violent as anything recorded from Vesuvius.

Mauna Loa has been the grand theater for lava flows. The first symptom of an eruption there, is the sudden illumination of the sky caused by the reflection of the molten lava. Mokuaweoweo has been empty and quiet, till all at once the end of the ascensive column brings in a flood of lava. If the sky is cloudy the light cannot be seen. Within a very few days there is an outburst from some point below on the side of the mountain, and the stream begins to flow, starting from an elevation of from 10,000 to 12,000 feet above the sea.

At the point of outbreak what has been called a terminal cone is formed—well seen in Plate 21, known as the Dewey crater, in 1899. These are made of lapilli, and may be seen at the sources of all the historic flows, as well as many more that are prehistoric. It would seem that hydrostatic pressure causes the lava to rise from an orifice perhaps hundreds of feet. The jet is highest at first, and disappears when the flow has ceased. The lapilli are simply the cold splashes of the liquid. The various facts relating to the dates, altitudes, duration and other elements of the flows can be seen best from tabular views.

MOKUAWEOWEO.

Year. Date.	Height.	Duration.	Conditions at Summit.	Elsewhere.
1780—	Pohaku o Hanalei			
1803—January 21	West or north side			
1832—June 20	13,000 feet	2 or 3 weeks	Bright light	
1843—Jan. 9 to late in February	13,000 feet	2 or 3 weeks	Clouds Jan. 10 to 17, bright light	
1849—May	Summit	2 or 3 weeks	Bright light just after activity in Kilauea	
1851—August 8	12,600 feet	3 or 4 days	Bright light	
1852—Feb. 17 to June	10,000 feet	4 months	Bright light for one day	
1855—Aug. 11 to Nov., 1856	12,000 feet	15 months	Bright light at first	
1859—June 23 to Nov. 25	10,000 feet	10 months	Bright light at first	
1865—Dec. 30	12,800 feet	4 months	Fountain in summit pit	
1868—March 27 to April 12	5,600 feet	Flow for 4 days	Bright light March 27 to 30	Earthquake wave; Kilauea active
1872—Aug. 10 into September	12,800 feet		Lava fountain 500 ft.	Earthquake wave at Hilo
1873—Jan. 6, 7	12,800 feet	2 days	Bright light; fountain	
1873—April 20 to October, 1874	12,800 feet	18 months	Brilliant fountains in June and August, 300 to 600 ft.	
1875—August 11	12,800 feet	1 week	Bright light	
1876—February 13	12,800 feet	Few days	Bright light	
1877—February 14 to 24	12,800 feet	10 days	Bright light	Submarine eruption
1880—May 1	12,800 feet	Several days	Fountain 900 ft.	Pele's hair in Hilo
1880—Nov. 5 to August, 1881	11,100 ft. (3 flows)	9 months	Bright light at first for a few days	
1887—January 16	11,000 and 6,500 ft.	10 days	Bright light few hours	
1887—November 26	12,800 feet	1 month	Smoke and steam	
1896—April 21	12,800 feet		Small lava fountains	
1899—July 1	11,000 feet	25 days	Bright light; fountains	
1903—Oct. 6 to Dec. 7	12,800 feet	61 days	Clouds, fountains	Sea disturbed Nov. 10
1907—January 10	8,500 feet (?)	14 days	Bright light	

From the tabular view of the eruptions from Mokuaweoweo and Mauna Loa the following facts seem to be established. There are five different features of which three are sometimes combined.

1. Every eruption commences with an influx of melted lava to the pit of Mokuaweoweo. In ten cases there was no farther manifestation of activity. These were in 1849, '65, '72, '73, '73, '75, '76, '80, '96, 1903.

2. There were eight cases where this lava proceeded from orifices very high up, from one to three thousand feet below the bottom of Mokuaweoweo and a considerable time was required to discharge the liquid. These were in 1780, 1832, '43, '52, '55, '59, '80, '99.

3. Three instances are on record where the fire issued from rents comparatively low down; preceded by vigorous earthquakes of short duration. These were in 1868, 1887, 1907. In 1851 the flow came from a high elevation and in other respects resembled those from low down.

4. In one instance, 1887, only smoke and steam issued from the summit.

5. Four submarine discharges or disturbances attended the other phenomena, in 1868, 1872, 1877, 1903.

6. Eruptions are more abundant in the rainy months—January to May.

7. The intervals between eruptions are irregular—from three months to eleven years.

ERUPTIONS FROM KILAUEA PREVIOUS TO 1820.

	A. D.
Active at first immigration under Wakea.......... ...	140
The same at second immigration in...............	1090
Average of one for every reign—three per century—fifty in all.	
Pele's conflict with Tamapua.....................	1175+
Pele's conflict with Keariikukua in Kapoho: Kariwari chased to the sea........................	1340-1380
Reign of Liloa—neighborhood of Keanakakoi......	1420
Time of Arapai at Kaimu.......................	1740
Three hills west of Kapoho, Honuaura, Malama and Mariu	1788
Keoua at Kilauea	1790

ERUPTIONS FROM KILAUEA AFTER 1820.

Date	Below Uwekahuna: Level of lava lake before eruption.	Below Uwekahuna: Bottom of pit after eruption.	Absolute height above sea of lowest pit.	Dome, height of.	Place of discharge.
1823—Between March and June	900	1700	2457	....	To southwest Kau, reaches ocean.
1832—June 20	715	1220	2937	....	Within the pit.
1840—May 30	650	1030	3127	....	To northeast—reaches ocean.
1849—May	350	1030	3127	300	Within the pit.
1855—October	?	1200	2957	600	Within the pit.
1868—April 2	600	1200	2957	....	To southwest Kau, reaches ocean.
1877—May 21 (Keanakakoi)	...	....	.....	....	No discharge.
1879—April 21	?	?	.....	....	Within the pit.
1884—January 22	...	....	.....	....	Submarine—off Puna.
1886—March 7	459	1017	3140	....	
1891—March 7	335	1102	3055	3955	Within the pit.
1894—July	402	724	3433	....	Within the pit.
1900—March 2 (unimportant)	...	917	3240	....	Within the pit.
1902—September 12	650	917	3240	....	Within the pit.
1906—August	...	....	.....	....	Submarine, Hilo.
1908—September 4	497	997	3160	....	Within the pit.

In the midst of accurate, possible and indeterminate figures for heights, I have selected those that seemed the best for the table, and assume that the molten lava rises gradually from the bottom of the pit after a collapse to the time of the next culmination. When there has been an uplift of the cindery blocks by flotation upon the liquid, mention is made of the top of the dome or cone resulting. For the depth of the pit after the first down-plunge, there is the original estimate of Mr. Ellis of eight hundred feet below the black ledge added to the trigonometrical measurement by Lieut. Malden the following year of nine hundred feet for the height of Uwekahuna above the black ledge. In 1834 Dr. D. Douglas figures the depth of the lowest pit at 1,077 feet. Assuming the correctness of the annual average rise of the pit from 1832 to 1840 of seventy-one and one-half feet, one hundred and forty-three feet must be added to 1,077=1,220 for the depth in 1832. His figure for the height of the western wall of seven hundred and fifteen feet above the black ledge would make the depth of the pit three hundred and sixty-two feet, to which must be added forty-three feet more to the molten lava.

For 1840 the figures are those of Captain Wilkes. After this date came the ascensive column of debris floated upon liquid lava three hundred feet high in 1848. As lavas were projected fifty to sixty feet higher in 1849 it is assumed that three hundred and fifty feet will represent the level attained by the liquid. For the depth of the pit there are no data; and it is assumed that its level may have been the same as in 1840. For the 1855 eruption we have only the estimates of Dr. Coan of six hundred feet for the dome above the bottom of the floor of 1840. Mr. Weld was satisfied that the depth of the pit was considerably less than 1,500 feet. If this be placed at 1,200 feet it will conform to the levels both earlier and later.

For 1868 the lower pit is estimated from various reports to have been six hundred feet deep. The black ledge is assumed to have been fifty feet higher than in 1840, or six hundred feet below Uwekahuna, making this pit 1,200. In 1880 the pit had become filled up and the middle portion was higher than its edges; the whole floor might be styled the black ledge.

Beginning with 1886 the figures for altitudes in this table are supposed to be correct though not entirely satisfactory.

The growth of the black ledge has been continuous. It has been measured at two points; at the base of the western wall, Uwekahuna, and where the trail from the Volcano House strikes it. The following table will show the probable figures:

Date.	Below western wall.	Below Volcano House
After the eruption of...........1823	900	900
1832	715	715
+Probably 20 feet greater.......1840	650+	650+
1868	600	483
1879	500	383
1886 (survey)	540	480
1900 (Shaughnessy)	...	465
1905 (Pickering)	...	410

The estimates for the altitude of the cone of Halemaumau have varied greatly, as may be seen by referring to the statements detailed previously. The one given in 1886 by the Government Survey appears to be the most accurate, making a cone sloping one hundred and sixty-three feet to the northeast wall, one hundred and twenty-five feet to the north, one hundred and five to the western side below Uwekahuna, eighty feet to the southwest. Miss Bird had recognized in 1874 the fact that Halemaumau was a hill top. In 1874 a barometric measurement gave it a height of one hundred and sixty-two feet. C. J. Lyons made its altitude one hundred and seventy-five feet in 1878. Prof. Brigham estimated it as three hundred and fifty feet in 1868.

In 1900 M. M. O'Shaughnessy measured it two hundred and seventy feet. In 1905 W. H. Pickering gave it as two hundred and thirty feet. Our latest estimate is about twenty feet less.

The features of the eruptions from Kilauea may be classified like those from Mokuaweoweo.

1. The influx of lava at the beginning was universal. In one case there seemed to be fire seen from Puna without further eruption as reported by Mrs. S. J. Lyman, Feb. 21, 1889.

2. Of eruptions from places high up may be cited the flows in Kilauea-iki in 1832 and 1868, and from Keanakakoi May 21, 1877.

3. There were three discharges from vents comparatively low down; in 1823, from the altitude of 2,700 feet; in 1840, from the altitude of 1,244, feet and in 1868 from the altitude of 1,700 feet. In the earlier history, the eruptions of 1175, 1340, 1740 and 1788 belong to that class.

4. Emanations of smoke and steam are almost continuous.

5. Only three submarine discharges are mentioned in the table, in 1884 and 1906 and 1907.

In addition to these Kilauea may add another conclusion, that in 1420 and 1790 there were explosive eruptions.

In many of the eruptions from our volcanoes the lava sinks into the earth and is lost sight of. There must be cavities in the interior capable of holding whatever fluid has been accumulated in the ascensive column. Some of them may be compared with the tunnels beneath the surface flows, or to their mouths, as discerned at the sea level. The deeper down the cavern the smaller will be its dimensions. Even the porosity of the basalts will disappear at great depths.

FIRE FOUNTAINS.

Mention has been made of the presence of small fountains in the lakes of Kilauea as being ordinary phenomena. During the eruptions from the greater caldera several lofty fountains of lava have been observed: and the evidence for their reality cannot be gainsaid. The annexed table shows the years when these fountains were seen, the heights of their place of outbreak above the sea (A) and the reported altitudes of the fiery jets (B):

	1852.	1859.	1865.	1868.	1872.	1873.
A	10,000	10,000	12,800	5,600	12,800	12,800
B	500-700	300-400	.....	200-600	500	300-600

	1875.	1880.	1887.	1896.	1899.	1903.
A	12,800	12,800	6,500	12,800	11,000	12,800
B	.....	900	80-200	500	250	500

The data for 1865 are from Mr. Green, who speaks of the fountain as *important,* nor does he state more definitely the conditions in 1875. The figure of 12,800 is intended to mean that the fountains issued from the floor of the caldera.

If the liquid arises like water because of hydrostatic pressure, the locations lowest down should show the highest jets, which does not seem to have been the fact. But the higher flows have proceeded from smaller apertures; the lower ones from rents or fractures which allowed the lava to discharge more rapidly and easily. This principle could not apply to the jets rising from the summit. Whatever force raised the lava to the floor of the caldera must have caused the fountains to play there, and also the protrusion of the liquid from crevices still higher, as has been reported several times.

In 1880 Mr. Goodale reported that the lavas were thrown sixty

to eighty feet above the brink of the crater when they were looking at the fountains upon the floor. What may have been protruded at this same time has been described by Rev. Janus M. Alexander in 1885.

Concerning the exudation of lava from seams at the summit W. L. Green writes: "Molten lava has often been seen to rise from cracks at the very summit of Mauna Loa, when the bottom of the crater of Mokuaweoweo remained undisturbed. This, however, only agrees with the phenomena which have been observed about Kilauea, and in addition to the explanation suggested in that case may merely mean that a free communication has been opened in those spots, whilst it has remained closed, or more restricted, at lower levels."

Add for Kilauea-iki in 1832 and 1868, and Keanakakoi for 1877, similar eruptions from the walls higher than the usual discharges.

SYMPATHY BETWEEN MAUNA LOA AND KILAUEA.

Much has been written upon the question as to how our two great volcanoes stand related to each other. Attempts have been made to show a species of parallelism in the volcanoes of the archipelago—the latest are by Professor Dana representing that Kaala, West Molokai, Lanai, Kahoolawe, Hualalai and Mauna Loa lie along one line, while the greater series is from Kauai through Koolau, East Molokai, Maui, Kohala and Mouna Kea to Kilauea. Mr. Green proposes the tetrahedral scheme, according to which all the volcanoes are near the intersections of two out of three sets of fissures disposed at angles of sixty degrees to each other. Both schemes agree in granting separate existence to Mouna Loa and Kilauea; the latter is not an appendage to the former.

The similarity of the rocks indicates a consanguinity. Both carry basalts with or without olivine, the same specific gravity and various minute details of composition.

Both are calderas and discharge their lava in similar ways.

But the main question is still, why should there exist only twenty miles apart two columns of liquid lava approximately 10,000 and 3,500 feet in altitude above the sea? If both come from the same reservoir why should not the discharge be from the end of the lower arm of the syphon, especially when the upper arm is filled? Or why should there not be a sympathetic action between the eruptions? Observers have often said that one volcano was asleep while the other was in action.

Mr. Green endeavors to show by experiments that liquids of

different densities will not necessarily stand at the same level when connected in separate upright glass tubes joined to a horizontal pipe containing a basal fluid. His assumption is that there is a variation in the densities of the Hawaiian lavas sufficient to sustain columns of varying lengths, particularly when they have different diameters; the smaller tubes suffer a greater proportionate loss of heat. The tempeature is maintained by convection currents. But he insists that a rise in the Mokuaweoweo column would not necessarily cause the Kilauea lavas to ascend; so that the sympathy supposed to exist would not be displayed.

The best starting point in this discussion is a comparison of the correspondencies and differences between the eruptions of these neighboring volcanoes, citing only those that are well known.

Mauna Loa.	Kilauea.
....	1823
1832	**1832**
....	1840
1843	....
1849	**1849**
1851-2	....
1855	**1855**
1859	....
1865-6	1866
1868	**1868**
1872-7	....
1877	**1877**
....	1879
1880-1	....
....	1886
1887	**1887**
....	1891
....	1894
1896	....
1899	....
....	1902
1903	....
1907	**1907**
....	1908

Averaging the figures so that when the eruptions occur exactly synchronously or during the same calendar years they will be on the same horizontal line, and having the eruptions that do not

agree placed between the others, the conclusions suggested are almost startling.

First the years of agreement are 1832, 1849, 1855, 1868, 1877, 1887, 1907. Three of those upon Mauna Loa, 1868, 1887, 1907, broke out only low down and were preceded by severe earthquakes. The most natural suggestion is that the simultaneous discharges were occasioned by the great depths of the lava: the mountain having refused to yield to pressure higher up. Because the pressure was intense the earthquakes were violent and fissures were produced, and the discharges though voluminous were effected very briefly. The 1855 eruption from Mauna Loa was one of the largest ever known. Those of 1832 may have been synchronous and not six months apart, as has been stated previously. The light on Mokuaweoweo in May, 1849, was not observed till after the fire was conspicuous at Kilauea, and Mr. Coan was not able to say that they were coincident, though the statement implies it. There have been, therefore, seven eruptions that were synchronous upon the two mountains. Second, upon the supposition that both columns had the same basal support, the discharge in the times between the joint eruptions was confined to one of the two volcanoes, the pressure not being sufficient to render both active. And there has usually been an alternation from one to the other. The greater column has sustained nine of the intermediate discharges, in 1843, 1851-2, 1859, 1865-6, 1872-7, 1880-1, 1896, 1899 and 1903; Kilauea has been active seven times, in 1866, 1879, 1886, 1891, 1894, 1902 and 1908. There may have been fire in Mokuaweoweo in 1823 and 1840 unrecorded, because of the absence of observers or because of concealment by clouds. Just why one or the other of these columns should have been affected to the exclusion of the other is not apparent.

Second, Mr. Green finds sympathy in the action between the two volcanoes not merely when the eruptions are synchronous but when increased activity has been observed in the supposed quiescent column either shortly before or after the main outburst. Lava does not exhibit as clearly as water the tendency to preserve a level, because it is viscid even at high temperatures. In all cases of the Mauna Loa eruptions at high altitudes the lavas in Kilauea have also been high, though not to the point of discharge.

In February, 1852, the lavas ran in a large stream on the northeast side of Mokuaweoweo. A month later Kilauea exhibited increased action. October 30, 1865, a brilliant light was displayed in Mokuaweoweo and continued for four months. No streams were known to have flowed from it, and no visitors

climbed to the summit. Just after the disappearance of the light new lakes of fire and cones appeared from Halemaumau to the northwest, north and northeast, as well as towards Keanakakoi. The surface was flooded for a distance of two miles and a breadth sometimes of half a mile, preventing access by the usual route to the great lake for months. Now the chronicler says no sympathy was exhibited by Kilauea with the summit fire; but Mr. Green calls attention to the fact that the moment action ceased at Mokuaweoweo it began in Kilauea. "The lava columns in the two mountains have been rising steadily together. The cessation of apparent action in the summit crater of Mauna Loa may merely mean that the immense mass of lava discharged over the bottom of the crater of Mokuaweoweo had finally cooled and sealed up the opening. But the gradual rise of the lava in Kilauea keeps on," and culminates a year and a half later in the double eruption of 1868.

The igneous manifestations on Mouna Loa from 1872-7 culminated in an earthquake and submarine eruption the last of February. The activity was soon transferred to Kilauea, as manifested at Keanakakoi in August, and almost continuously about Halemaumau till the collapse of April, 1879; after which it was quiet for a couple of months.

Both the volcanoes were active in May, 1880, in South Mokuaweoweo and Halemaumau. The lava had been steadily rising in both columns and continued ready for a discharge till November, when relief was afforded by the flow from Puka Uahi, lasting for nine months and reaching to the margin of the village of Hilo.

The next action was at Kilauea in 1886, there being lakes of lava varying slightly in detail but gradually increasing from 1880 till the minor collapse in March, 1886. Mokuaweoweo seemed almost extinct till the time of the double eruption in January, 1887. The scene of activity was again exhibited in Kilauea alone, culminating in 1891 and 1894. After that came the two displays of 1896 and 1899 upon Mauna Loa and the contemporaneous inactivity of Kilauea. The latter awoke again briefly in 1902 and Mauna Loa in 1903, but there was not much stirring in either pit till the last recorded double eruption in 1907.

Third. The intervals between the periods of joint action are somewhat suggestive of an approximate twenty year cycle, the figures being in order from 1832, 17, 6, 13, 19, 20. Possibly the 1855 episode was a supplement, as the intervals of 6 and 13 add up to 19.

Fourth. The old notion that volcanoes are safety valves is not so far astray after all. It is pressure from below that gives rise

to eruptions. If relief is not afforded by discharges at high levels, the tension brings on earthquakes low down, and after great chasms have been opened the lava flows out and then quietude is restored.

It is conceivable that the retaining walls might be strong enough to withstand the pressure down to or below the sea level. If so the probability would favor the coming of a violent explosion like those from Vesuvius or Tarawera; unless the discharges in the ocean as in 1844, 1877, 1884, etc., afforded the proper relief.

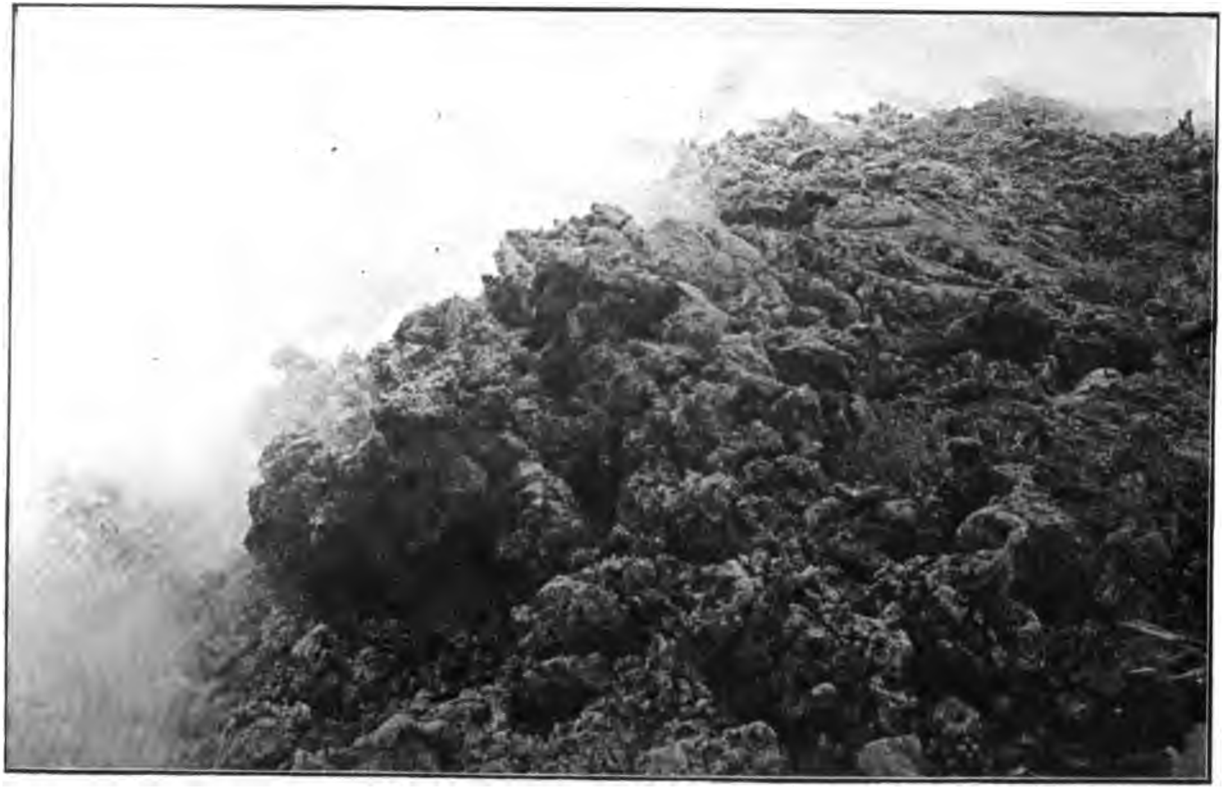
PAHOEHOE AND AA.

The terms *pahoehoe* and *aa,* expressive of the two principal classes of lava are of Hawaiian origin, whence it is evident that the natives early appreciated their peculiarities. They have now taken a fixed place in volcanic terminology in spite of the protest of Professor T. G. Bonney, and have been recognized as existent in other countries and older formations.

Pahoehoe is the most common of the two. The name signifies having the aspect of satin, a shining smooth surface. It is quite hummocky because the liquid stiffens very quickly after exposure. Water is smooth in rivers, but when the temperature falls below the freezing point the surface will bulge much like the lava. Plate 51 represents pahoehoe from the flow of '80-1 near Hilo. On the right the bulging is more domelike: and it represents a stream later than that on the left. The superposition of the later flow is apparent in the photograph. Standing by this variety of lava as it forms, one sees that it is a stream of liquid material, and if a stick be thrust into it red lava will flow out. On the left side the domes show the wrinkling called ropy structure, convex down stream, because the current has a greater velocity in that direction. The crust is flexible and is modulated by the motion of the liquid beneath. Other figures from Kilauea show the same structure. The surface may be more glassy than the substratum because the more siliceous part is lighter than the rest. Beneath the billowy surface may be vacant spaces, left by lava which has run out, leaving tunnels, which often are lined by stalactites. The rate of the flow is variable, depending on the degree of fluidity and the slope. Most observers overrate the velocity. It took nine months for the flow of '80-1 to reach Hilo, a distance of thirty miles.

The study of the aa has not yet revealed to us its proper nature and origin. All travelers avoid crossing it if possible unless the highway surveyor has pulverized its roughness, when it makes an

Pahoehoe from the flow of 1881.



Aa from flow of 1887.

admirable road. Those who climb Mauna Loa travel miles to avoid crossing it.

Two examples are very prominent; the first between Kilauea and the Halfway House, Plate 26. It starts from near Puu Ulaula, descends the south slope and when near Kilauea turns to the southwest. For many years this curved ridge figured as the "flow of 1823," but this label has proved to be erroneous. The roughness of it where traversed by the road for six miles beggars any possible descripton. The fragments are larger than usual, from three to five feet in length. The other illustration is the long embankment below Aina Hou near Humuulu sheep station, situated as if it were a spur from the flow of 1843, with scarcely any descent. It was an older flow, creeping along like a caterpillar, and effectually imprisons the cattle in the mauka grassy area. Plate 50 shows aa from the flow of 1887.

When minutely examined the aa ridge is seen to be composed of bristling ragged rocks, incoherent, with an occasional smoother piece like a bomb. The fragments in the original streams are not cemented together any more than cobble stones in a gravel bank. The blocks may be a few cubic inches to a thousand feet in size, dumped to a height of twenty to forty feet; they are brittle, not scoriaceous, slightly vesiculate, easily broken down. Professor Dana says, "the reader's conception of it will be feeble at the best if he has not already had a view of chaos." When in motion D. H. Hitchcock thus describes it: "The whole broad front of the then sluggish stream was a mass of solidified lava twelve to thirty feet in height, moving slowly along by breaking and bearing onward the crushed covering; along the whole line of its advance it was one crash of rolling, sliding, tumbling, red hot rock, no liquid rock being in sight; there were no explosions, but a tremendous roaring, like ten thousand blast furnaces all at work at once. The rough blocks lie piled together in the wildest confusion, many as large as ordinary houses—and the movement is slow."

Others refer to a red heat among the blocks, while the fused rock rarely exudes, but insist upon a heavier molten fluid beneath supporting the bristling fragments, and a rolling action in the front part. I have sometimes compared the onward motion to the flow of burning anthracite coal, when unintentionally by the opening of the grate beneath a quantity of it escapes.

When the stream has been covered for ages the bristling character of the fragments is modified; the surfaces are somewhat smoothed: and in the illustrations to be cited from the older rocks

the structure becomes concentric, and the mass resembles an agglomerate.

Judge Hitchcock says further of the aa: "This is always the first lava running from all outbursts on Mauna Loa and Kilauea. Pahoehoe does not run from under aa, but commences near the fountain head as pahoehoe. The liquid lava under aa is aa, not pahoehoe, as seen in 1880-1 by Professor Alexander and myself. A stream of liquid aa flowed from under aa rock and cooled into aa."

At first it was supposed that the aa was a clinker field; the breaking up of a partially cooled pahoehoe stream, like river ice in a spring freshet. Later it was thus expressed by Captain Dutton, "When these lavas are discharged they come up out of the ground in enormous volumes, are intensely heated, and are very liquid. As they become cooler they become viscous. The cooling takes place upon the surface of the mass while the interior still remains hot and preserves a viscous liquidity. The fields of aa are formed by the flowing of large masses of lava while in a condition approaching that of solidification. The same stream may exhibit pahoehoe or aa according to the circumstances attending the flow, and the final form which the stream takes is quite independent of the chemical constitution of the lava."

Professor Brigham says: "The aa seems to occur when the lava meets with an impediment, which gives way just as the lava is granulated, rolling the spongy mass over, and building up huge piles from which the liquid drains away."

W. L. Green remarks that the aa looks like a great scoriaceous railway embankment "down the center of which the lava continues to flow in a molten state, forming ultimately a solid arched crust which falls in from contraction, though the tube may be miles in length. The convexity is the same in all streams, and there is no necessity for invoking the presence of water."

Other observers insist that the first lava issuing from the Hawaiian volcanoes is always aa.

E. P. Baker writes: "I have stood by a wholly molten stream of lava which miles below was cooling into aa."

Dr. S. E. Bishop follows D. H. Hitchcock's general statements, and claims that the vesicles of pahoehoe are spherical; but as the fragments roll along half cooled, the vesicles are pulled out of shape and ragged misshapen forms are developed.

Professor Dana concludes: 1. That the differences between pahoehoe and aa must be connected with some condition in the region flowed over. 2. That the conditions must be such as to allow extreme liquidity in the one and a pasty state in the other.

3. That some deeply acting cooling agency has acted upon the lava to make aa. 4. The cooling was from below upwards and suggests; 5, that subterranean moisture may have been the cooling agent.

To make this suggestion worthy of consideration, it would be necessary first to show from the actual distribution of the aa that moisture was more abundant beneath it than under the pahoehoe. Water appears in streams and pools, or to a limited extent as rainfall; but does not seem to show any partiality for the one class of the lavas rather than the other. There was an interesting illustration of the behavior of a lava stream in Catania, Sicily, in 1843. A stream of lava had invaded the cultivated land. Suddenly its extremity was seen to swell up like an enormous blister and then to burst, discharging a quantity of steam with a volley of fragments, solid and liquid. Sixty-nine persons were injured. The catastrophe appeared to have been caused by the lava flowing over a subterranean reservoir of water, thus suddenly generating steam that caused the explosion.

Other ways in whch the lava streams have been affected by water have been cited, none of them resembling aa.

The aa is not confined to Hawaii. I have noticed streams of it in California when passing through the Mojave desert. It has been recognized by J. Morgan Clements in the ancient rocks of the Vermilion iron bearing district of Minnesota.[48] He found many bunches of igneous rocks having a concentric structure, and refers them to the pseudo-bombs of aa, based upon the descriptions of Professor Dana. Since then I have referred diorite dikes in the Silurian rocks of the Ammonoosuc district of New Hampshire to the same category.[49] Another reference may be to Newfoundland; and I recognize the same structure in some of the Triassic traps near Greenfield, Massachusetts. In examining sections of the Hawaiian basalts in many localities one can easily recognize beds of aa among the various components. In these cases the rough surfaces have been smoothed down. Bunches may be recognized by their concentricity, and possibly by an irregular vesiculation. They must not be confounded with the spherical or rounded masses analogous to the columnar structrue.

[48] Monograph XL of the United States Geological Survey, 1903.

[49] New studies in the Ammonoosuc District; Bull. Geol. Soc. Amer, Vol. 15, 1904.

AREAS OF THE FLOWS.

Mr. E. D. Baldwin estimates that the flow of 1907 covered 9,000 acres of rough land, and sent forth a volume of over 200,000,000 cubic yards of basaltic material. Some of the earlier flows are compared with this. The flow of 1855 covered over 15,000 acres of land and discharged 600,000,000 cubic yards of rock. The flow of 1880-1 covered 20,000 acres of land and discharged over 540,000,000 cubic yards of rock. The flow of 1859 was comparable with that of 1855. These estimates do not allow for the material that passes off into subterranean cavities and are suggestive rather than accurate.

By inspection of the map of Hawaii, one can see delineated the areas occupied by the historic flows from both the volcanoes. Above 9,000 feet the surface is a complete network of lava streams finely exposed because of the absence of vegetation. It would be an interminable task to unravel these twists. To some extent their relative edges could be deciphered by noting the degrees of freshness exhibited. The whole dome of Mauna Loa, down to the base of the cone, nearly 30,000 feet, is but a congeries of lava flows. When one considers how little the bulk of the mountain is made up of the few flows delineated on the map, and how small a portion of the whole mass this can be, he is overwhelmed by the certainty that there were millions of streams, and that many millions of years must be assumed in order to say how old the mountain is. It must have commenced to build up long before the Tertiary period.

BASALT VOLCANOES.

Volcanoes may be classified by the petrographical character of the lavas which they emit: for the fluidity of the material, the temperature of fusion and the shapes of the cones are determined by the assemblage of the constituent minerals. The materials are spoken of as basic or acidic. The basic lavas are those carrying iron, lime and magnesia in large amount, and small proportions of silica or the lime-soda feldspars, the augitic and allied ferromagnesian silicates, iron-oxide, but no free quartz. The rocks thus made up are termed basalts, dense and fine grained, with or without olivine. They are the most fusible of the lavas, melting at the temperature of 2250° F. The acid lavas carry much silica, potash feldspars, hornblende, mica and quartz and are termed *trachytic* and *rhyolitic*. They fuse with difficulty from 2700° F. to 3100° F. Between these two classes are intermediate forms, composed of lime soda feldspar, augite or hornblende and fre-

quently quartz, and have a medium degree of fusibilty, 2520° F.

The form of the cone is dependent upon the degree of fusibility. Those of the basalt order, easily liquified, build up cones with slopes of less than ten degrees; those of the trachytic order build up cones with slopes from twenty-eight to thirty-five or forty degrees. It is the degree of fluidity or pastiness of the lava that produces the shapes of volcanoes, modified by the presence of tuff or cinders.

With these distinctions in mind it is easy to perceive that most of the Hawaiian volcanoes belong to the first order as they are basaltic and have low angles of slope. Mauna Loa is the finest example, being a magnificent dome, concave above where the basalts have accumulated, but with a concave rim at the base, because of eruptions low down. One may be at a loss within a mile of the summit to know where the pit is. That was my experience in 1883 when my guide lost his way because the marks upon which he had relied for his knowledge of locality were covered with snow. The surface is nearly flat for several square miles in extent, and the pit is not seen till you are close upon it. The form of the dome of Mauna Loa is shown in Plate 15, as seen from a distance of twenty miles. In a circle of five miles around the pit the mean slope is about three degrees. Radial lines to the different points of the compass show slopes from about four to six and two-thirds degrees from the summit to the shore line. The slope of the cone of Halemaumau inside of Kilauea is not much more than a single degree. The outward slopes of Kilauea are about one and a half degrees to the northeast and southwest. The south slope is steeper because of displacement by faulting.

These domes are elongated, being elliptical rather than circular. Mokuaweoweo has the course of N. 35° E. for the northern part and N. 20° E. for the southern part, as shown upon the map. About the same trend prevails from the flows near Kahuku to the summit, and beyond to Mauna Kea. To reach the sources of the flows in the south edge of Hamakua connected by the fault line, the direction is about northeast. This southern divergence is paralleled by the similar bend southeast from Kilauea.

Variations in the character of the lava are conceivable, as of rhyolite in the place of basalt; in which case the features of the cone might be altered. Or the supply of heat may be diminished, and allow the outburst of cinders and tuffs: or should water enter the conduit from below, explosive eruptions might occur, like those of the other types of action. The tuffs and ashes emitted explosively upon the other islands seem to be connected with the later lateral monticles.

The most important feature of the basalt volcano is the caldera or pit crater, and this is thoroughly characteristic of Hawaii. The eruptions are always within or from rents connected with the central body of lava. This feature dominates thoughout the archipelago, and there are nowhere else upon the planet finer examples of this type of action.

Briefly summarized the Hawaian type of volcanic action is expressed by the caldera, by basalt, the most easily fused of all volcanic rocks, by the development of an ascensive column from whose summit lakes of molten lava accumulate and flow away intermittently, by a sympathetic uprising in adjacent calderas, by the building up of domes rather than cones from material forced up from below by subterranean power, by displaying magnificent fountains of fire, and usually by rather quiet eruptions and few earthquakes. By way of contrast Vesuvius possesses a cone with curved sides; while basaltic it is composed largely of the trachytic element, builds up cinder cones and discharges bombs and stones in an explosive manner. It was the common doctrine at the time of my visit in 1866 that the eruptions followed the filling of the crater with debris, on the principle that the free egress of volcanic matter was impeded, and that the obstacle must be removed. In 1866 no crater existed, it had been filled up; and true to the principle stated, an eruption ensued in the following year. The question whether there may be an ascensive column has not been studied at Vesuvius. Mineral chlorids are plentiful, as suggested by the greater nearness to the sea, four miles, as contrasted with Kilauea nine and Mauna Loa twenty.

There are some minor points of agreement between the types. They both have periods of filling up, discharging and collapsing, or intermittent action. Some of the vents are fissures at the base of the mountain. The streams of lava form tunnels and show the ropy structure. Both present the spectacle of a dark cloud said to resemble a pine tree, which consists of vapors carrying ashes that are spread over the adjacent country.

Vesuvius is a small volcano compared with Kilauea. The cavity left in Halemaumau in 1886, say half a mile across and six hundred feet deep, represents the size of a crater of Vesuvius. At Kilauea this was but a minor discharge.

Possibly it may be better to claim that every volcano has its own type of eruption. Thus, Pelée, in Martinique, was characterized by the terrible hot blast of steam and vapors directed down the mountain side, with mud flows and the rising of the obelisk; Krakatoa by a tremendous explosion with wonderful attendant atmospheric phenomena; Tarawera by the discharge

of ashes, mud and scoria from a long rent accompanied by geyser-like action; Baldaisan by the ascent of a dense column of steam and dust with many explosions, a landslide, no flow of lava, and geyser-like action, all accomplished in six hours; Stromboli, by a constant ebullition of liquid lava, known to be active for 2,000 years, and so easily affected by the weight of the atmosphere that it serves as a barometer to the passing ships.

LUNAR AND HAWAIIAN PHYSICAL FEATURES COMPARED.

Geologists have not been slow to recognize volcanoes in the photographs of the lunar surface taken by astronomers. G. Poulett Scrope presents comparative maps of the craters about Naples and upon the moon, and others have discussed the resemblance between them. In 1905 Professor W. H. Pickering of Harvard Observatory visited the Hawaiian Islands to study their volcanic features, and in 1907 he explored the volcanoes of the Azores, with the intent of learning what light their contours throw upon the lunar craters. He had determined that the lunar craters correspond better with the Hawaiian or "engulphment" type than with the Vesuvian, characterized by explosive eruptions, before starting. The explosive volcanoes have the habit of blowing the craters into fragments in time of eruption; whereas the calderas of Hawaii and the Moon discharge their lavas internally without any important fractures of the walls. The lunar volcanoes are from two to twenty times larger than the terrestrial ones, while the force of gravitation in the Moon is only one-sixth as great as it is upon the Earth. This would allow the former body to support craters much larger than the latter.

Of the three classes of terrestrial craters, the tuff and cinder cones, and the lava craters, only the last need to be studied in this connection, although there are with us examples of the others. The third series may be classified as cones, pits, rings and bowls, most of them very diminutive by the side of their lunar relatives. Other formations are the caves, channels, cracks, blow holes or spiracles, pinnacles and ridges.

Mauna Loa is the finest example of a lava cone, and conceiving the ocean removed, as there is no water in the Moon, it is quite worthy of comparison, with its height of 30,000 feet and a base of one hundred miles. Every island in the archipelago is of the same nature, and usually with several cones present. Bullialdus in the Moon with a crater thirty-eight miles in diameter, has the same general contour. Other examples are Kahakau in Molokai, Kuohi, the sixth crater near Kilauea, Halemaumau, Kilauea-iki and several upon Hualalai. These have no elevated borders, are

simply holes in the ground, and are compared to some of the lunar *maria*.

The lunar rings are represented by Schickard, Phocylides and the Sinus Iridium, Plate 48AB. The first has a diameter of one hundred and thirty-four miles, with a depth of two miles. The Sinus Iridium is a good illustration of a *mare*, with a flat top. The rings of Kilauea used by Professor Pickering to illustrate this phase, are the encrusted edges of the lakes of 1891 and 1894. Their rarity upon the earth, compared with their abundance in the moon, may be explained because here they are not permanent. Upon the moon with a diameter of from twenty to sixty miles and a depth of two miles, the destruction of the walls by falling down would not be so common.

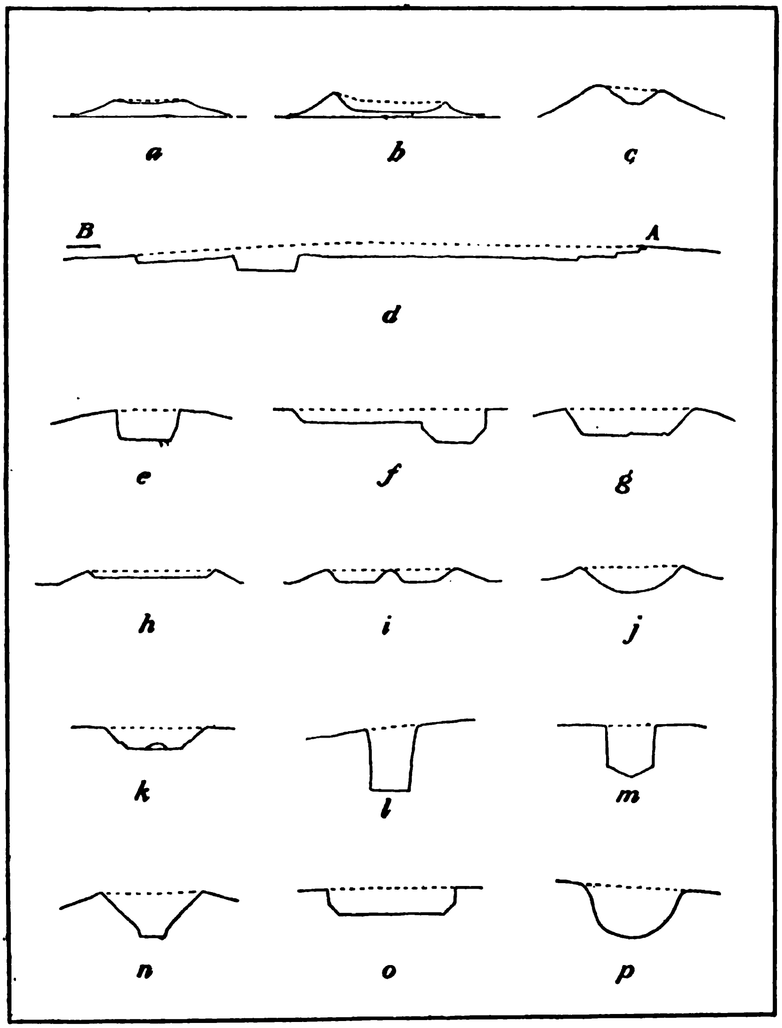
The lunar craters have three kinds of floors; either with a central peak, several small craters or without conspicuous detail. The Hawaiian craters carrying central peaks are uncommon, unless Kilauea with its central cone of Halemaumau may be considered as one. Professor Pickering uses several illustrations, see Plate 49, as one near Humuula, Hualalai and east of Kilauea. The ridge along the central line of Haleakala, four hundred feet long and one hundred and fifty feet high may be of this character.

The lava bowls are illustrated by Aloi, the third crater east of Kilauea, and upon Hualalai. Their number upon the moon is very great, being ten times more than all the other depressions combined.

Plate 49 is copied from Professor Pickering's book, illustrating the various cones, pits, rings and bowls found in Hawaii which help in the elucidation of the lunar craters. As their relative sizes are unimportant I have not copied the detail of their scales.

a-b, Tuff cones of Punchbowl and Diamond Head; c, cinder cone on Mauna Kea, compare Plate 12B; d, the caldera of Kilauea from north to south; e, lava cone in Haleakala, compare Plate 11B; f, lava pit, sixth crater near Kilauea; g, lava cone and ring, and h, ring from Hualalai; i, lava ring with central cone near Humuula; j, lava bowl on Hualalai; k, l, m, n, p, lava piles from Hualalai; o, Alealea or fourth crater near Kilauea.

The spiracles represent rather uncommon phenomena at Kilauea. Steam rises readily in water, less easily in lava because of the greater degree of resistance to the upward movement. The projectile force must depend upon the viscidity of the lava. Because of the liquidity of basaltic lavas, the jets in Kilauea rise only a few yards; the drops fall back still in the melted condition and the jets dance in very lively manner. When somewhat stiffened



Lunar and Muudane Craters, after W. H. Pickering.

A. Schickard. Phocylides.

B. Sinus Iridium.

View of Keanakakoi.

the lava mud falls around the vent and cones result, having apertures in the top through which the steam rushes noisily. A still later episode is where the explosive force throws the pulverized fragments high into the air as lapilli, ashes or dust. Various observers have watched this rising bubble in Stromboli, with its bursting and cinder projections.

The lunar spiracles are of larger dimensions than those seen in Kilauea or Hualalai, some of the latter being a thousand feet high. The pinnacles are also more conspicuous upon the Moon than upon the Earth. The same is true of caves and tunnels resulting from the hardening of the surface of lava flows, allowing the liquid to run till the supply is exhausted. These caves were found better developed in the Azores than in Hawaii, where lakes of fresh water and solid cones also appear.

Faults or cracks are common in all volcanic regions, especially mentioned in the palis south of Kilauea and in the fractures produced in the eruption of 1868. Upon the Moon these cracks are known as *rills,* and are very numerous; and may be also related to the canals upon Mars.

Keanakakoi (Plate 45) is also cited as an illustration of Lunar craters with smooth floors.

It is not practicable to set forth farther the similarities between the Lunar and Hawaiian volcanic features. They are to be explained primarily as phenomena characteristic of volcanoes in whatever world they occur; and secondarily as belonging to *Calderas,* of which the most celebrated examples are in Mokuaweoweo and Kilauea. See *Lunar and Hawaiian Physical features compared, Memoirs of the American Academy, Boston,* Vol. XIII; and *Appalachia,* Vol. XI, No. 4.

APPENDIX.

A. EARTHQUAKES IN HAWAII.

Hawaii is regarded as a land where earthquakes are frequent and powerful. Since the invention of apparatus fitted to record the presence of these shocks, and the attention paid to their study in Japan, and under the auspices of the British Association For the Advancement of Science, so great has been the advance in our knowledge of these phenomena, that it is just to speak of the "New Seismology": whatever had been written more than twenty years ago is of slight consequence in the comparison. Under the direction of Professor Milne sixteen seismological stations have been equipped with seismographs at as many important localities all over the world, and the reports from them studied and collated at the Isle of Wight in England. One of these instruments has been established at Sisal, near Ewa, on Oahu. Little has been reported from this station to the public, save that it served to allay apprehension at the time of the great earthquake in 1906 in San Francisco. There is a crying need for the establishment of a Seismological Observatory near Kilauea, similar to the analogous institution upon Vesuvius, where the phenomena connected with the volcano can be observed, as well as those relating to earthquakes generally. The director of the Vesuvian Observatory has been able to send out authoritative warnings of disaster, which have been utilized by the public like the storm predictions from the National Weather Bureau at Washington. The Hawaiian volcanoes are fortunately situated at a considerable distance from settlements, and people congregate to witness eruptions rather than flee from them; but there is no part of the United States where the study of volcanic and seismic phenomena can be better prosecuted.

In the history of our volcanoes attention has been called to the occurrence of earthquakes, just as visitors happened to have noted them. A better record has been kept at Hilo by Mrs. Sarah J. Lyman, extracts from which have been published from time to time. Although ascribed to the Rev. D. B. Lyman, the first one of them is that published by Captain Wilkes in his Narrative, stating what the disturbances were between 1833 and 1841. After that time the same lady continued her record down to the end of 1885, when her life was ended. The family maintained the record several years longer.

Three classes of seismic disturbances have been observed in Hawaii; first, those connected with the volcanoes; second, those that have been propagated by stresses in the earth away from the islands, sometimes called *tectonic*; third, the sea waves, where the jar has been communicated to the water of the ocean. Those of the second class are of less account locally than the others. It is important that they should be recorded by the seismographs and correlated with the same shocks in other lands. The inhabitants of the Territory need not be apprehensive of any seismic disaster, except those who live near the volcanoes of Mauna Loa and Kilauea, or in the path of the sea waves.

Of the volcanic quakes, that of 1868, centering in Kau, is the most important. It is esteemed as one of the most forcible series of shocks connected with a volcano ever described. The statements respecting these disturbances given in our account of the eruption of Mauna Loa in 1868 will recall their terrible nature. All edifices, the trees ,animals and men were affected; and sea waves were started at the coast. Many lives were lost. No observers in that day attempted to determine the various elements of the quake; but its connection with an eruption from Mauna Loa is now universally conceded. As in the fable, it may be said that the mountain was groaning to be delivered, and the birth was the deluge of lava shot up high into the air and flowing to the sea. By this occurrence it was evident that some of the eruptions from Mauna Loa were not of the quiet sort. Nineteen years later another eruption from near by was preceded by earthquakes numerous and violent, and still a third in 1907. And attention has been called to many other similar eruptions coming from the bases of both Mauna Loa and Kilauea in prehistoric times, which may have been equally violent.

When the records of the seismograph at Sisal are published, it will be possible to learn how important the tectonic quakes have been in our archipelago. So far as known, none of this class of shocks have been particularly severe.

Quite a number of the sea waves have made themselves felt among the islands, and attention will be called to a few of them.

EARTHQUAKE WAVES.

On the 7th of November, 1837, there was an earthquake in Chile, and a sea wave started by it was felt at the Hawaiian Islands; also at Tutuila in the Samoan group. The phenomena observed at Hilo are thus described by Rev. Titus Coan:

At about 7 P. M. the sea at Hilo was observed to retire far

below its usual low-water mark. In a few moments afterwards the water returned in a gigantic wave, rushing to the shore with great velocity, and breaking upon the beach with a noise like a peal of thunder. All the low grounds in the neighborhood of the beach were instantly submerged, and a large number of houses were swept away. So sudden and unexpected was the catastrophe, that many of the inhabitants were engulphed in the flood, and compelled to struggle for their lives. The sea remained upon the land about fifteen minutes, when it retired beyond the line of low water, and after a short interval returned again, but with less violence. It afterwards continued to vibrate for a time, gradually decreasing at each oscillation, until it attained its usual level.

The scene of distress which this phenomenon produced was great. Hundreds of natives were at a meeting near the seashore, when the wave rushed upon them and left them struggling amidst the wreck of their worldly effects. Some of them were carried to sea, while others were dashed upon the shore, surrounded by the fragments of their houses, which had been broken to pieces, together with the timbers, frames, calabashes, etc.

Cries of distress came from all sides, as well from those who were struggling for life, as those who had come down to their relief. Parents were rushing to and fro, looking for their children, husbands for their wives, children for their parents, each inquiring for the other, with wailings and hallooings. The whole, combined with the roar of the sea, rendered the scene one of thrilling interest. Fortunately an English whaler, the Admiral Cockburn, of which James Lawrence was commander, was lying in the bay at the time. He in a most praiseworthy manner lowered his boats, and kept them cruising about the bay, in search of the natives, many of whom were picked up, wearied and exhausted, and by this timely aid their lives were preserved. Not a canoe was left on the shore to assist in this work. Mr. Lawrence affirms that the water ran past his ship at the rate of eight knots an hour, and that the soundings were reduced from five to three and a half fathoms, which left a great part of the bay dry.

EARTHQUAKE WAVE OF 1868.

On the 13th of August, 1868, at 5:05 P. M. an earthquake was started off the coast of Arica, Peru, said to have had a duration of ten minutes. At 5:32 P. M. the first of a series of waves from fifty to sixty feet high rushed in upon the land,

penetrating a considerable distance. J. E. Hilgard published an account of these waves in the report of the Coast Survey for 1869; and his conclusions were accepted and published by the highest authorities. The wave was reported at Coquimbo eight hundred miles in three hours, Hawaii (Hilo) in fourteen hours and ten minutes, in Japan upon the following day. The same wave had been reported earlier at San Diego, San Francisco, Cal., and Kodiak, Alaska, with the times respectively of ten hours and fifty-five minutes, twelve hours and fifty-six minutes and twenty-two hours, at the average of three hundred and sixty-nine, three hundred and forty-eight and two hundred and eighty-two miles per hour, and distances of 4,030, 4.480 and 6,200 miles. To reach Lyttleton, N. Z., and Sydney, Australia, 6,120 and 7,440 miles, the time required was nineteen hours and one minute and twenty-three hours and forty-one minutes at the rates of 322 and 314 miles per hour. In 1880 I saw a placard upon a cocoanut tree in Hilo, situated as much as fifteen feet above the sea level, stating the fact that an earthquake wave was noted at that altitude upon the date mentioned.

The velocity of a sea wave depends both upon the wave-length and the depth of the water. Knowing the wave length and therefore what ought to be their free velocity, and knowing their actual velocity by observation, the difference gives the retardation by dragging; and from the retardation may be calculated the mean depth of the ocean traversed. The results stated were a depth of 12,000 feet between Japan and San Francisco, and 18,500 between Peru and Honolulu.

By a study of the facts as they were related to Hawaii it is apparent that erroneous observations were relied upon. To reach Hilo, 5,460 miles, the waves moved at the rate of three hundred and eighty-five miles per hour; to reach Honolulu, 5,580 miles, the rate was four hundred and fifty-four miles. Now the path of the wave from Arica was the same to both Hilo and Honolulu; and there is a manifest incongruity in saying that the rate to Hilo was three hundred and eighty-five and to Honolulu four hundred and fifty-four miles per hour. The wave reached Honolulu in twelve hours and eighteen minutes, the greater distance by the same route, and Hilo in fourteen hours and ten minutes, the less distance. I addressed an inquiry to O. H. Tittman, the Superintendent of the Coast and Geodetic Survey, and received the following reply:

"In reply to your inquiry of the 15th instant, concerning the discrepancy in the times of the arrival of the earthquake wave from Arica, Peru, at Hilo and Honolulu, I have to state that because

the disturbance reached the Hawaiian Islands near midnight and because the time is given to whole hours only, it seems probable that no accurate observations were there made upon this phenomenon. In Petermann's "Mittheilungen," Vol. 15, 1869, pages 222-226, Prof. Hochstetter has given the same values in his collection of times at places where the earthquake wave was felt. He notices discrepancy of the Hawaiian Islands values and uses a mean between the two."

It is, of course, impracticable at this late date to discover what the original records for Honolulu should have been, so as to be able to give correct figures. It will be observed that the rates per hour for all the localities except Honolulu fall below four hundred. Hence the table as published by Professor Hilgard may be esteemed as correct with only one exception. I think it better to eliminate the Honolulu observation altogether, and with it the estimate of the greater depth of the ocean between Hawaii and Peru as compared with that upon the side towards Australia. From the Advertiser published shortly after the event, it is learned that between Aug. 7 and 18, 1868, this same wave arose to the height of twelve feet upon the windward side of Maui. There are better observations derived from the transmission of waves in later years from which to draw conclusions. One such may have been the one passing Hilo May 10, 1877, which originated in South America. The damage done by it is graphically set forth in the following letter from Mr. Severance:

The account is in the form of an official report of Sheriff Severance, addressed to Marshal W. C. Parke:

Hilo, May 11, 1877.

W. C. Parke, Esq., Marshal.

Dear Sir: We have had a great disaster at Hilo. On Thursday morning the 10th inst., at about 4 o'clock A. M., the sea in the bay was seen to rise and fall in an unusual manner, and at 5 o'clock it swept in, in a mighty wave, washing up and into nearly all the stores in the front of the town, carrying off a great deal of lumber and all the stone wall makai of the wharf. The perpendicular height of the wave (as we have since ascertained by levelling with the lamp-post on the wharf) was 12 feet 3 inches above the ordinary low water mark.

But at Waiakea the damage was frightful; every house within a hundred yards of the water was swept away. The steamboat wharf and the storehouse, Spencer's storehouse, the bridge across the stream, and all the dwelling houses were swept away in an

instant, and now lie a mass of ruins far inland. Five lives were lost, and numbers bruised and had limbs broken. The body of one woman was found by the boats off Honolii. The boats of the American whaleship Pacific, Capt. Smithers, lying in the harbor, picked up six people who were swimming for their lives in the Bay. The Pacific was lying in 4 fathoms of water, but she grounded when the sea receded, and then would be whirled round and round as the sea came in again. All expected to see her drag ashore.

The sea continued to rise and fall all day. I timed one of the tides in the morning about 7 o'clock, and from its lowest ebb to its full flood was only about 4 minutes. It rose about 14 feet perpendicular height in that time. In the afternoon in the space of one hour, the sea rose and fell three times with a height above half tide of 7.10 1-2 and 3 feet each time.

Mr. Rose's tin shop was floated off its foundations, and is now in the middle of the street.

The poor people at Waiakea are in a sad state; houses destroyed and utterly destitute; their goods and furniture scattered far and wide on sea and land. The water was 3 inches deep in Conway's store, when the 5 o'clock wave came in. The wave at Waiakea must have had a perpendicular height of 16 feet, to have taken the bridge and wharf where they now lie. The water swept completely over Cocoanut Island, and the hospital there has disappeared. The oil of the bark Pacific, stored in Spencer's storehouse ,has been nearly all found scattered about among the bushes and trees ,a long ways in shore from the place where the storehouse stood.

There has been nothing like this tidal wave since the year 1837, nearly 40 years ago, when many grass houses were destroyed.

I have made a careful investigation of the extent of the disaster, and find as follows, viz.: Thirty-seven dwelling houses entirely destroyed; seventeen badly injured; five people drowned and killed; seven badly injured; one hundred and sixty-three left homeless and destitute; seventeen horses and mules drowned—this is exclusive of the government property. Sisson estimates his loss (in lumber) at several thousand dollars. The total damage has been estimated as high as $12,000 to $14,000, which is, I think, a low estimate, as several thousand dollars worth of stores belonging to the ship Josephine, and about thirty barrels of oil, of the Pacific, are still to be accounted for.

Yours, in haste,

L. Severance.

B. THE PLACE OF ORIGIN OF THE MOON.

Astronomers generally believe that the moon was once a part of the earth from which it has been separated by fission when in a somewhat plastic condition. The original material had greater volume than when the separation took place: and by condensation the speed of rotation increased until by centrifugal force the moon was born. Professor G. H. Darwin conceives the earth to have been drawn out to be pear-shaped—and by continued distortion a sort of knob formed at the small end, and eventually separated. I do not understand that Darwin favored the idea that this separation could take place except that the plasticity approached liquidity, in which case no mark would be left at the point of separation. Professor W. H. Pickering conceives that the earth was so solid at this time that its main topographical features were the same as now, and that the mass eliminated left behind a scar, which corresponds to the bed of the Pacific Ocean. As it concerns the history of Hawaii, it has seemed best to refer to the subject here.

Upon examining an artificial globe having the land and water represented upon it, and placing it so that the pole will be located one thousand miles northeast of New Zealand, very little land will be seen, and the outline of the Pacific will be circular—most of the land will occupy the other hemisphere. What can be more natural than that the Pacific depression occupies the place where the moon sloughed off?

The volume of the moon is equivalent to a solid whose surface is equal to that of all our terrestrial oceans, and whose depth is thirty-six miles. Supposing the crust of the earth to have been thirty-six miles thick, three-quarters of it could have been carried away to form the moon, and the remainder might have been torn in two for the continental masses, which floated upon the surface as two islands.

The specific gravity of the earth as a whole is about 5.6; of the moon 3.4; the surface of the continents 2.7; the upper half of Mauna Kea 2.1; the lower half 3.7; and this lower portion is conceived to represent the specific gravity of the liquid upon which the hypothetical islands floated. The average gravity for the whole of Mauna Kea is 2.9. The gravities of the various basalts of Hawaii range from 2.82 to 3.20. Because the gravities of the moon and of the heavier lavas are nearly alike, Professor Pickering concludes that the doctrine of the derivation of the origin of the moon from the Pacific ocean is substantiated. That the lunar and Hawaiian volcanoes

are very much alike, as set forth earlier in this volume, does not affect the present question.

Prof. Pickering enters into specific explanation of the continental and insular forms, which to us are less convincing than the speculations of W. L. Green, who would object to the derivation of the moon from the Pacific alone because of the near approach of the earth to fluidity. The surface would not have been rigid enough to retain the distinctions of continent and ocean at this early period, and he has clearly explained a better view of the origin of the earth's physical features.

It seems to us that a consideration of the protuberant mass of the earth manifested in the equatorial regions, throws light upon the degree to which a modulation may take place. In former days it was claimed that the flattening of the poles proved igneous fluidity in the earth's early history. After stating that there had not been an appreciable shortening of the earth's diameter for the past two thousand years, or since astronomic observations began to be taken, the late Professor Benjamin Pierce remarked that were the earth solid this equatorial bulge would have been formed by the pressure of the agencies that caused it to exist. If so, how much less could the so-called scar of the Pacific have maintained its irregularities since that early period when the two spheres separated? Hence it does not appear to us that the theory of the Pacific scar maintained by Professor Pickering can be substantiated.

C. USE OF THE SPECTROSCOPE.

Allusions have been made to the use of the spectroscope in determining the character of the elements. The most satisfactory observations were made by Professor William Libbey of Princeton University in September, 1893, and reported in the *American Journal of Science* for 1894, page 371; but are incomplete. The indications were for gases under high pressure, carbonic oxide, hydrocarbons and other lines undetermined, thought to be probably copper and sulphur. Bluish green flames reported by several persons have been referred to hydrogen.

The most important fact is the presence of hydrocarbons. Were it not that this compound has been detected elsewhere in lavas, it could scarcely be believed that it should be found here. The older geologists have supposed that this substance was of organic origin, and hence not to be looked for in the incandescent lava; but the spectroscope makes no mistakes. To the above must be added steam, the vapor of water. Chlorides have been

looked for but are not certainly recognized in the Hawaiian volcanoes. They are common where ocean water has had access to the fires from below, especially in the eruptions of the explosive type. Ammonium and copper chlorides are common at Vesuvius.

The doctrine is now being freely advanced that the water and hydrocarbons evolved from volcanoes constituted a part of the original magma of the earth, while not excluding the entrance of rain waters from above. It is certainly a fact that after a storm old vents like the Dewey crater upon Mauna Loa discharge steam liberally. The sites of most of the old lakes and fissures in Kilauea are located by the issuance of steam after rains. I recently counted fifty such emissions in the caldera, and more at the sulphur banks and crevices away from the main pit.

D. ANALYSES OF HAWAIIAN IGNEOUS ROCKS.

Copied from Dr. H. S. Washington's Professional Paper No. 14, of the United States Geological Survey.

FIRST ARE THE SUPERIOR ANALYSES.

CLASS II. DOSALANE.

Rang 2—Sub-rang 4.

	39	101	102	18	19	10
SiO_2	58.06	48.71	45.61	49.01	46.30	50.16
Al_2O_3	18.21	18.87	15.98	16.29	17.95	17.97
Fe_2O_3	4.87	3.18	8.25	7.61	6.21	2.23
FeO	2.01	8.00	11.60	4.89	6.79	6.25
MgO	1.59	4.85	3.75	3.62	3.67	4.70
CaO	3.29	9.87	6.42	9.79	8.17	11.85
Na_2O	6.12	4.15	3.50	3.82	3.92	3.50
K_2O	2.75	1.52	1.82	0.80	0.89	2.80
H_2O+	....	none	0.27	....	....	none
TiO_2	1.88	1.81	1.15	3.93	5.35	trace
P_2O_5	0.65	trace	0.72	0.49	0.53	trace
MnO	0.36	trace	1.20	0.27	0.26	0.30
SO_3	0.05	....	....	0.20	0.06	....
S	0.05	....	....	0.02	0.05	....
CuO	0.10	....	....	0.10	0.17	....
Sp. Gr.	....	2.99	2.94	....	....	3.03

39—Andesite, Waimea, Kohala, A. B. Lyons.
18—Kohala, A. B. Lyons.
101—Crater walls, Kilauea, Silvestri, Basalt.
19—Waianae, Oahu, A. B. Lyons.
102—Crater walls, Kilauea, Silvestri, Basalt.
10—Crater walls, Kilauea, Silvestri, Augite Andesite.

CLASS III. SALFEMANE.

	9	10	58	59	60	61	20	21
SiO_2	49.45	47.63	49.80	48.04	47.61	56.79	51.63	49.88
Al_2O_3	13.97	15.02	13.76	14.62	16.09	15.09	12.10	13.79
Fe_2O_3	8.10	8.15	3.09	9.18	7.00	5.34	8.67	9.65
FeO	11.17	10.40	11.97	11.68	10.60	5.58	3.10	2.61
MgO	1.90	3.50	5.02	2.17	3.10	5.92	9.40	6.12
CaO	5.92	6.87	10.25	7.66	8.15	10.21	9.17	9.59
Na_2O	5.05	4.92	3.00	4.00	2.98	3.67	3.10	3.30
K_2O	1.75	1.80	1.15	1.28	1.15	0.90	0.30	0.17
H_2O+	1.19	0.30	trace	none	0.70	....	....	....
TiO_2	trace	0.12	0.95	trace	0.39	3.25	2.47	3.97
P_2O_5	0.16	0.08	0.22	0.45	trace	0.29	0.76	0.26
MnO	0.85	0.80	0.10	1.91	1.72	0.49	0.30	0.67
SO_3	....	....	....	....	....	2.54	0.07	0.09
CuO	....	....	....	....	....	0.18	0.48	0.14
S	....	....	....	....	....	....	0.02	0.02
Cr_2O_3	....	....	....	....	....	....	trace	trace
Sp. Gr....	2.74	2.76	....	2.78	2.93	....	....	....

9 and 10—Basalt, Crater walls, Kilauea, Silvestri.
58, 59, 60—Basalt, Kilauea, Silvestri.
61—Pele's Hair, A. B. Lyons.
20—Basalt, Waianae, Oahu, A. B. Lyons.
21—Basalt, Koolau Range, Oahu, A. B. Lyons.

	69	70	71
SiO_2	50.76	49.20	48.82
Al_2O_3	14.75	14.90	15.22
Fe_2O_3	2.89	4.51	5.72
FeO	9.85	12.75	9.65
MgO	6.54	3.90	4.55
CaO	11.05	9.20	10.40
Na_2O	2.70	1.96	2.10
K_2O	0.88	0.95	0.90
H_2O+	....	0.10	none
TiO_2	....	1.22	1.16
P_2O_5	0.26	0.42	trace
MnO	0.41	0.28	0.67
Sp. Gr....................................	....	....	3.01

69—Pele's Hair, A. H. Phillips.
70—Lava of May, 1883, Silvestri.
71—Kilauea, Basalt, Silvestri.

The analyses following are styled "inferior," and include tuffs, ashes and decomposed rocks.

	72	73	74	75	76	77	78	79	80	81	82	83	84
SiO_2	50	48.60	45.30	51.77	47.44	47.33	40.11	37.82	36.85	35.86	34.81	24.62	4.54
Al_2O_3	22.80	25.45	14.90	15.66	16.51	17.96	12.40	13.16	11.97	12.10	33.18	23.89	41.35
Fe_2O_3	14.15	17.55	10.87	8.46	15.33	12.64	14.64	14.11	13.90	7.82	23.03	37.85	40.87
FeO	4.05	1.20	8.20	6.54	3.19	0.51	trace	0.14	6.54	8.09	2.34	2.08	2.52
MgO	1.93	0.98	3.78	4.95	8.80	3.97	11.68	11.75	10.73	9.72	0.39	0.99	0.37
CaO	3.17	2.20	6.58	9.56	6.02	6.29	12.24	13.39	9.00	12.08	trace	trace	trace
Na_2O	1.99	1.38	5.23	2.17	1.60	3.67	2.72	1.66	4.13	6.23	trace	1.41	trace
K_2O			1.77	0.96	0.30	1.10	0.96	1.49	0.29	1.93	trace	trace	trace
H_2O+	0.33	1.87	1.20	....	....	....	....	....	....	....	....	....	....
TiO_2	0.42	trace	trace	....	....	4.84	....	....	4.05	2.90	4.89	8.12	8.99
P_2O_5	trace	trace	0.25	....	0.61	1.05	0.57	0.82	1.25	1.08	0.39	0.24	0.63
MnO	0.97	trace	0.91	0.82	0.37	0.64	0.25	0.24	1.13	0.39	0.28	0.25	0.08
Sp. Gr.	2.77	2.80	2.79	....	....	....	....	....	....	....	....	....	....
CO_2	....	....	....	....	....	....	4.15	5.56	....	....	....	....	....
SO_3	....	....	....	....	0.06	0.07	0.17	0.15	trace	0.27	0.31	0.40	0.55
CuO	....	....	....	....	0.08	0.15	0.11	0.07	0.10	0.25	0.37	0.27	0.26
S	....	....	....	....	....	0.07	....	....	0.14	....	....	....	....
FeS_2	....	....	....	....	....	....	....	0.05	....	1.40	....	....	....
CoO	....	....	....	....	....	....	....	....	0.04	....	....	....	....

72, 73, 74—Basaltoid, Silvestri, Kilauea.
75—Stalagmite, Basalt, A. H. Phillips, Kilauea.
76—Basalt tuff, Salt Lake, Oahu, A. B. Lyons.
77—Basalt, Mt. Kohala, Waimea, A. B. Lyons.
78—Basalt tuff, Diamond Head, A. B. Lyons.
79—Basalt tuff, Punchbowl, A. B. Lyons.
80—Basalt scoria, Punahou, A. B. Lyons.
81—Basalt lapilli, Punahou, A. B. Lyons.
82—Basalt, Honolulu, A. B. Lyons.
83—Basalt not fresh, Hilo, A. B. Lyons.
84—Basalt weathered, Kaneohe, Oahu, A. B. Lyons.

Two additional analyses are those of W. F. Hillebrand of (1) Trachyte-obsidian, and (2) Trachyte from Puu Waawaa and Puu Anahulu, made for Whitman Cross.

No.	1	2
SiO_2	62.19	62.11
Al_2O_3	17.43	*w*
Fe_2O_3	1.65	*w*22.97
FeO	2.64	*w*
MgO	0.40	......
CaO	0.86	0.85
Na_2O	8.28	6.89
K_2O	5.03	4.82
H_2O+	0.39	1.60
H_2O-	0.14	
CO_2	0.02	trace
TiO_2	0.37	......
ZrO_2	0.04	......
P_2O_5	0.14	......
SO_3	none	......
Cl	....	......
Cr_2O_3	trace	......
NiO	none	......
MnO	0.32	......
BaO	0.03	......
SrO	none	......
Li_2O	trace	......
	99.93	......

"These rocks fall within the Dosalaur class. Since the feldspars predominate over nephelite to an extreme degree and there is no anorthite in the norm, the rock falls in the perfelic order *germanare,* and the peralkalic rang *umptekase.* Soda strongly dominates potash, and thus the glass belongs in the subrang *umptekose,* but is so close to the corresponding subrang of the Persalanes that the position is best shown by the name *nordmarkose-umptekose.*"—From the Journal of Geology, Vol. XII, No. 6, October, 1904.

E. BIOGRAPHICAL NOTES.

Of those who have explored the volcanoes or have been identified with original views in respect to vulcanism, the origin of the

earth's physical features and certain atmospheric phenomena connected with eruptions, Titus Coan, Sereno E. Bishop, W. T. Brigham and C. E. Dutton stand out conspicuously. Plate 52 shows the features of four of them. Citations from the publications of all of them have been freely made in this book.

James Dwight Dana graduated at Yale College in 1833; was a member of the U. S. Exploring Expedition from 1836 to 1842; wrote reports upon its Geology, upon Crustacea, Corals and Coral Reefs; was Professor of Geology at Yale from 1855 for forty years. His books upon Mineralogy and Geology have never been excelled. Kilauea was visited by him in 1840, 1841 and 1887. His latest views of Hawaiian Volcanoes were published in Characteristics of Volcanoes, 1891.

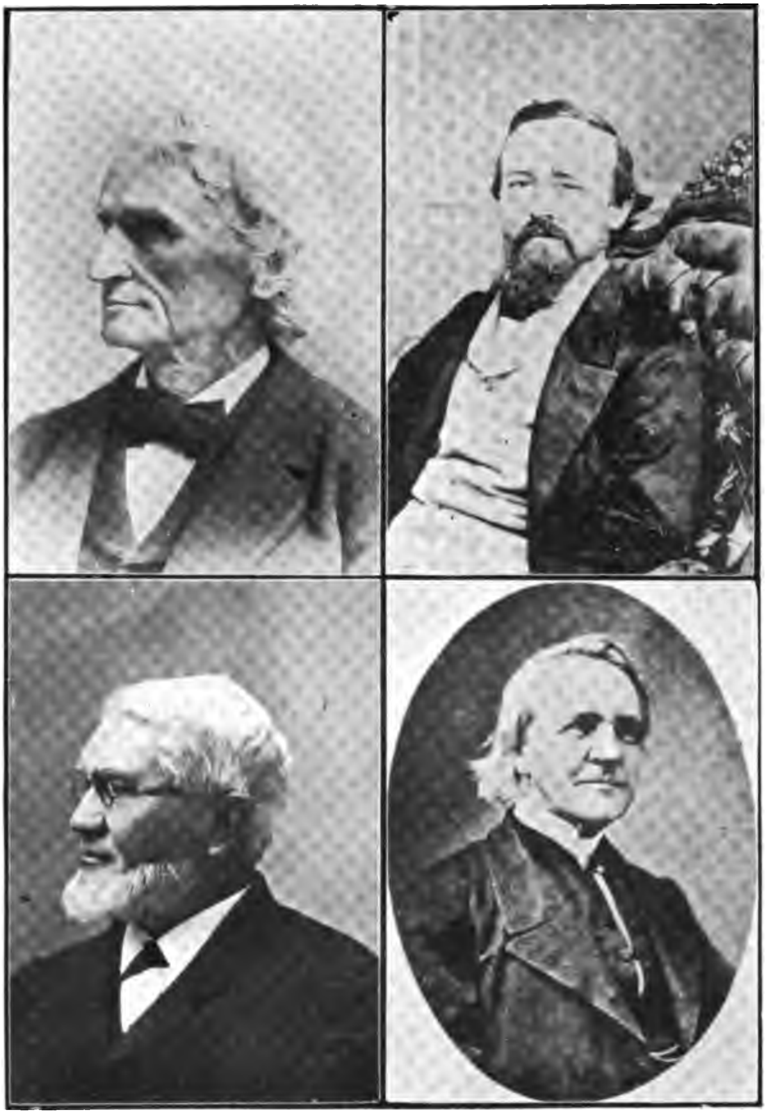
No name is more thoroughly associated with Hawaii than that of Dr. Titus Coan, who was in the service of the A. B. C. F. M. from 1835 to 1882. Familiarly he was known as the "Bishop of Kilauea." He wielded a facile pen, and described everything that happened after 1840. Except for his visits we could not have procured a satisfactory history of the volcanoes between 1840 and 1880. His papers were published mostly in the *American Journal of Science,* whose editor, Professor Dana, was his particular friend.

William Lowthian Green, (1819-1890) born in London, came to Honolulu in 1848. Engaged in mercantile pursuits he took great interest in scientific studies. Being a man of affairs, he was repeatedly called into the service of the Kingdom of Hawaii between 1874 and 1889, acting as Premier after 1880.

The memory of William Lowthian Green will be honored henceforth because of his success in showing why the earth has assumed its present relief. Our most eminent authors have heretofore failed to discover the principle regulating the contraction of the earth, almost to the point of denying the existence of any rational element in the development. The orographic features have been clearly made out, the stability of continents and ocean beds affirmed, two causes of topographic trends nearly at right angles to each other have been detected; but how do these facts match? It has not been because no one has claimed the discovery; for Elie de Beaumont enunciated many approved principles. Geologists saw that his network of pentagons, as well as the dodecahedral lines of Richard Owen, would not stand the test of a rigorous analysis; and hence had no patience to listen to the overtures of Mr. Green with his tetrahedral symmetry.

Upon examining a terrestrial globe it is easy to block out the

PLATE 52.



J. D. Dana
S. E. Bishop

W. L. Green
Titus Coan

tetrahedron with the apex at the south pole and the angles proceeding northerly by the way of South America, Africa and Australia; with basal angles in North America, Scandinavia and northeastern Asia, and a north polar ocean resting upon the base of the figure. In a measure these salient points have existed as projections ever since the Archean period, for the figure must have been fashioned prior to the beginning of sedimentation. The following features of the earth's topography may be mentioned as explicable by this theory and not by any other:

1. Most of the land is in the northern hemisphere, stretching eastwards and westwards along parallels of latitude.

2. There are practically three double continents north of the equator: America, Africa-Europe, Asia-Australia, with pyramidal projections pointing into the southern ocean. The northern portions are broader than the southern.

3. At the north pole the land is depressed, supporting the Arctic ocean.

4. The continents and oceans are antipodal to each other, land being always opposite the water.

5. The southern hemisphere is mainly ocean, with a central mass of land at the pole and terrestrial projections radiating from it.

In the further study of details the hextetrahedron is employed, and the twenty-four triangles of that figure are seen to be spherical, not plane. Hence the earth's figure as thus conceived departs very little from the sphericity usually ascribed to it. Oblateness is a feature added to the contractional shape by the earth's rotation, and modifies the figure somewhat—more particularly by the movement of the water which must assume its level. Mr. Green has carried out the details of the network of fissures at angles of sixty degrees with each other only for the Hawaiian Islands.

There are two facts requiring further explanation: first, the separation of all the continents by a mediterranean line of depression, and second, the eastward projection of the southern peninsula. The explanation is supplementary to the presence of the tetrahedron, as propounded by Mr. Green. The tetrahedron rotates around the polar axis. At first the different points moved with equal velocities; but when the protuberances became accentuated the three upper ones were retarded, while the regions south of the equator moved more rapidly. Thus the hextetradehron has been submitted to torsion, which has produced a line of continuous rupture near the equator corresponding to the well known volcanic belt or earthquake zone. Hence, it is easy to understand

why the lines of elevation have failed to correspond exactly to the tetrahedral angles. Borrowing the language of crystallography, if the whole earth is a hextetrahedron, the line of rupture is a twinning plane, not necessarily coincident with any element of the crystal. The position of this plane is further justified by referring to the tides produced in the primitive earth while the crust was still thin.

The equatorial bulge of the earth is understood to produce the precession of the equinoxes. As the three northern protuberances must have some effect for similar reasons, Mr. Green finds it in the inclination of the ecliptic.

M. de Lapparent, in adopting this theory, finds in it the explanation of the excess of the attraction of gravitation in the northern hemisphere. The sea is attracted by these three protuberances; but in the middle of each of the oceanic depressions the surface of the water would tend to flatten, as the latter is nearer the center of the earth.

In studying the collapse of spherical bodies, Mr. Green quotes from experiments of Mr. Fairbairn. (Useful information for engineers.) Hollow glass spheres were reduced to fragments, and nothing could be learned as to the method of their collapse. Rubber spheres immersed in water tend towards a tetrahedron. Soap bubbles in the air present a slightly tetrahedroidal form when compared with air bubbles in water. Some organic bodies, like nuts and tetraspores, exhibit shapes indicative of a collapsing tetrahedral body. Cylinders show very satisfactorily a flattening from three different directions after collapse.

The sphere of all regular solids embraces the greatest volume with the smallest surface. The tetrahedron has greatest surface with the smallest volume. Hence a collapsing spherical envelope "tends to adopt that form which most quickly and permanently disposes of the excess of its linear dimensions about the diminishing volume of the contents which support it." The force producing collapse is simply the weight of the earth's crust.

PUBLISHED WRITINGS OF W. L. GREEN.

1. Extinct coast craters of Oahu. Sandwich Islands monthly, Nos. 1, 2, and 3, for April, May, and June, 1856.

2. On the cause of the pyramidal form of the outline of the southern extremities of the great continents and peninsulas of the globe. Edinburgh New Philosophical Journal, 1857.

3. Vestiges of the molten globe. Part I. London, 1875.

4. The southern tendency of peninsulas in connection with the

remarkable preponderance of ocean in the southern hemisphere. Letter to Sir John Lubbock. Honolulu, March, 1877.

5. The Hawaiian Islands on the reseau triangulaire. Letter to W. T. Brigham. Written, April, 1876, printed 1877, Boston.

6. The volcanic problem from the point of view of Hawaiian volcanoes, Honolulu, 1884.

7. Vestiges of the molten globe. Part II. Honolulu, 1887.

8. Notice of Prof. J. D. Dana's "Characteristics of Volcanoes," Honolulu, 1890.

Sereno Edwards Bishop (1827-1909), graduated at Amherst College in 1846 and at Auburn Theological Seminary in 1851. His father, Rev. Artemas Bishop, was one of the first missionaries sent out by the A. B. C. F. M., 1822-1873. Returning to his native islands he was engaged in missionary occupations upon Maui for thirteen years, when he changed his residence to Honolulu, supporting himself by land surveying and writing for the press. He was a stout champion of the "faith once delivered to the saints," believing the Bible to be the Word of God, to be interpreted in the light of common sense. He had clear views of public duty, and never hesitated to say what he believed to be right. Between 1885 and 1895 his editorials upon vital questions were veritable thunderbolts.

He perceived the true relation between the famous sky glows, atmospheric haze and solar coronas and volcanic eruptions; and because he was its first observer one of these phenomena has received the name of the Bishop's Ring. December 31st, 1908, almost the last day previous to his final sickness, he discerned all these atmospheric phenomena in the skies and recognized them as indicative of a great volcanic eruption in some distant part of the earth. Our record of the history of Kilauea and Mauna Loa shows that his statements have been freely quoted and accepted.

William T. Brigham graduated at Harvard College in 1862. Was an instructor of botany at his Alma Mater and became much interested in volcanoes and earthquakes, early compiling a paper upon the earthquakes of New England. In 1864-5 he made a careful survey and study of Kilauea, and ascended Mauna Loa. The results of this work made a quarto volume 126 pages, published in the Memoirs of the Boston Society of Natural History in 1868; which include besides his own survey a history of the Hawaiian eruptions and a general review of the geology of the islands. A supplement added descriptions of the eruption of 1868. Later he visited Central America and published a book upon the volcanoes of Guatemala. He visited Mauna Loa again

in 1880. In 1888 he was chosen to be the Director of the Bernice Pauahi Bishop Museum in Honolulu. He received the honorary degree of Doctor of Science from Columbia in 1894. No scientific man has paid more visits to Kilauea than Dr. Brigham, amounting to more than two score, extending over forty-four years; and no one is better qualified by his natural ability and opportunities for observation to describe the vicissitudes through which our noted volcanoes have passed. His latest recommendation is that a permanent scientific observatory be established at Kilauea, where notes may be taken with the best instruments, of earthquakes, the diurnal changes of level of the dome of Halemaumau, the temperatures of the molten lava and steam jets, the analyses of the ejecta and spectroscopic investigations.

Clarence E. Dutton graduated at Yale College in 1860. He joined the Ordnance Corps of the United States Army in 1863. He became First Lieutenant in 1867, Captain in 1873, and retired in 1890 with the rank of Major. For several years he was connected with the Geological Survey and presented reports upon the Geology of the High Plateaus of Utah, the Tertiary History of the Grand Canyon District, the Charleston Earthquake, Mt. Taylor and the Zuni Plateau. His familiarity with igneous rocks rendered his report upon the Hawaiian Volcanoes of special importance. Since his retirement he has published a book upon Earthquakes.

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Hitchcock, Charles H.
AUTHOR

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